A PRACTICAL TREATISE ON RAIL-ROADS, AND INTERIOR COMMUNICATION IN GENERAL;

WITH

Original Experiments,

AND

TABLES

OF THE COMPARATIVE VALUE OF

CANALS AND RAIL-ROADS.

ILLUSTRATED BY ENGRAVINGS.

By NICHOLAS WOOD,

COLLIERY VIEWER.

"Every accession which Man gains to his knowledge, is also an accession
"to his power; and extends the limits of his empire over the world
"which he inhabits." BACON.

LONDON:

PRINTED FOR KNIGHT AND LACEY,

PATERNOSTER-ROW;

SOLD BY J. AND R. AKENHEAD, NEWCASTLE-UPON-TYNE; AND WESTLEY
AND TYRRELL, DUBLIN.

M.DCCC.XXV.

LONDON:
PRINTED BY W. LEWIS, 21, FINCH-LANE.

DEDICATED,

By Permission,

TO THE RIGHT HONORABLE

LORD RAVENSWORTH,

JAMES ARCHIBALD STUART WORTLEY, Esq.

AND

THE TRUSTEES OF THE LATE

EARL OF STRATHMORE,

BY

THEIR MUCH OBLIGED

AND HUMBLE SERVANT,

NICHOLAS WOOD.

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

ERRATA.

Page	*Line*	*For*	*read*
37	17	Fig. I. Plate I. II.	Fig. I. II. Plate I.
43	—	beyond	before
47	—	nails	rails
48	4	or downright	a downright
—	5	buoying	bearing
49	12	stem	stone
54	3	Walton	Wallsend
59	6	run	turn
62	29	injurious	ingenious
68	25	oxydegerent or rusting taken, *read* oxydation taken place	
71	20	pressing	forming
74	4	pressure	occurrence
—	17	team	train
80	18	chain	chair
84	14, 17, 26	chain	chair
106	32	when	where
110	25	Birthy	Birtley
—	27	Inpeth	Urpeth
127	16	Merthyn	Merthyr
131	22	Hetton	Heaton
135	29	sloping or slipping ground, *read* slipping round	
142	24 & 26	chain	chair
144	17 & 19	ditto	ditto
161	9	one inch and a half	half-an-inch
167	8	28 .11	56 .11
172	3	force	form
184	13	chain	chair
206	15	410	400

INTRODUCTION.

In offering these pages to the Public, little explanation is perhaps necessary; the acknowledged importance of Rail-road conveyance, and the intense anxiety existing in the public mind, respecting the relative value of Canals and Rail-roads, as species of internal communication, render any information concerning them of interest; and, if that information is founded on the result of experiments performed on a working scale, it is conceived that, whether they tend towards establishing the one

system or the other, they will be equally entitled to attention.

The want of practical information on the subject of Rail-roads, has been much lamented; detached observations and opinions have at times been circulated, but little has been done towards the exhibition of the subject in a systematic manner.—The want of experiments on the friction of carriages,—the want of detailed observations on the performance of horses, and of other kinds of motive power, have alike been the subject of regret among those interested in such enquiries; and little more than mere conjecture has transpired in the writings of all those who have not been more immediately concerned in the practical application of this mode of conveyance.

In attempting to supply these defects, considering the importance of the subject, some apology may be necessary; but in giving the result of facts, which have come under my knowledge in the course of professional practice, and also of several experiments made with the express view of obtaining the requisite information; it is trusted, that it will be a sufficient excuse for any errors, when it is considered, that the path is almost an unbeaten one, and that little, except general observations, has hitherto been published.

The greatest care has been used in the prosecution of the different experiments, and the most minute details are given, in order that the reader may be able to judge of the credit to which they are entitled; my object has been to furnish practical

data on the subject, and in doing so, not to assume any theory, or deduce any proposition, which is not supported by experiment; and if, in doing this, I have rendered the work less suited to the taste of general readers, or have fallen into prolixity in the description of the details; I trust that it will be attributed to my desire of rendering the subject clear and familiar to the capacity of every one, whether acquainted or unacquainted with the technical phraseology of the enquiry.

It would be too much for me to assume that I have supplied all the information of which the subject is susceptible; on the contrary, I wish it to be understood, that what is herein contained must be considered only as an approximation. It will be sufficient, if what I have done be of use

in the practical elucidation of this species of internal communication, and serviceable in establishing a more correct judgment of its nature and utility.

I shall, therefore, without further comment, proceed to give an outline of the nature of the work; and, in doing so, will point out some omissions, which want of time and opportunity have obliged me for the present to postpone.

Chapter I.—Contains an introduction on the history of the various species of internal communication, with their successive and several transitions into the present modes.

Chapter II.—Comprehends an historical account of the introduction of Rail-roads, with a description of their gradual improvement from wooden to cast. and

malleable iron-rails, illustrated by several drawings.

In preparing this chapter, the remote date of the first application of Rail-roads to the transit of goods, has somewhat obscured this part of the subject, and rendered it not quite so perspicuous and clear as I could have wished. In following up the history, I have however endeavoured to trace the successive steps, from one improvement to another, which I have illustrated by requisite drawings. I have also given drawings of several rails at present in use, in cases where general opinion seems to have concurred in pronouncing their superiority. Perhaps, some readers may find that no notice is taken of various kinds of rails, which they may think important. I have, however, given all those which materially

differed from each other, and where such difference appeared to me to present a real improvement; but, in doing so, it will be necessary to state that I have confined my observations exclusively to those at present in use; and this remark will suffice for those who do not find in any of the other parts of the work, notice taken of several schemes recently offered to the attention of the public.

Chapter III.—Contains a description of the form and construction of carriages used upon Rail-roads,—in which I have not attempted to give the particular form of the body of the carriages, as these must vary with almost every kind of goods, and would have imposed upon myself and my readers an endless, as well as an useless task. I have, therefore, confined my observations

to those parts of the carriages which were common to each kind, and peculiar to the road.

In CHAPTER IV. I have introduced a division of the various lines of inclination of Rail-roads, into those suitable for each distinct kind of motive power; and, although I found it extremely difficult to fix a proper line of demarcation between each, yet, I trust, the division will be useful, not only in practice, but also as the means of conveying a more distinct idea of the degree of inclination proper for each description of motive power.

Whenever the nature of the road permitted, as in the case of the self-acting and engine-planes, I have given formulæ for calculating the effect of carriages; de-

scending by their gravitating force, these, though perhaps not possessing strict mathematical correctness, will nevertheless be sufficiently accurate for practice.

In this chapter I have also given a history of the various sorts of loco-motive engines, as far as the extent of my enquiries enabled me, which I have followed up by particular descriptions, illustrated by drawings, on a copious scale, of the different engines at present in use.

CHAPTER V.—Comprehends Experiments on the strength of cast and malleable iron rails, from which is deduced a practical rule for determining the strength necessary to carry different weights on other Railroads.

In CHAPTER VI. is given a series of

Experiments on the friction or resistance of carriages moved on Rail-roads. These Experiments, being varied both with respect to weight and velocity, it is trusted, will be found useful, especially, as the want of the necessary data is justly acknowledged. They were multiplied until no doubt could be entertained of their accuracy; and the details are given with every minuteness, that the reader may be able to judge of the dependance which may be placed upon them.

Some ambiguity having arisen, respecting the law of resistance of carriages moved at different velocities upon Rail-roads, I have attempted, by a comprehensive and minute illustration, assisted by diagrams, to define the proper ratio, which I have derived from Experi-

ment; and which, it is trusted, will be the means of elucidating the true law of such resistance.

Chapter VII.—Ropes being most generally employed in dragging carriages up ascents, or lowering them down from one level to another on Rail-roads, by the aid of fixed steam-engines, or by the force of gravity, the friction of these will form a subject of enquiry of considerable importance. This chapter contains, therefore, a series of Experiments, on the friction of ropes, on several engine and self-acting planes in actual use; from which is deduced, a theorem for ascertaining the friction of ropes employed in dragging carriages upon any Rail-road.

Chapter VIII.—Comprehends a set of experiments, observations, and deductions,

on the various species of motive-power used on Rail-roads, divided into four parts, viz.

Self-acting Planes,
Fixed Steam-engine Planes,.
Horses, and
Loco-motive Steam-engines.

In Self-acting Planes the moving power being the force of gravity, the action of which is well-known, and that action being communicated to the carriages by the medium of ropes; a practical theorem is given, founded on the friction of ropes, as ascertained by Experiment.

The effective performance of fixed steam-engines is, also, illustrated by four examples of engines dragging carriages up ascents on Rail-roads, from whence will be derived a rule for practical application.

Some regard should, however, be observed with respect to the effective power of high-pressure engines, acting solely by the expansive force of steam. In the elucidation of the loco-motive engines, it will be found, that the effective energy upon the load, compared with the pressure upon the piston, (the latter being calculated by the elasticity of the steam in the boiler) depends in a great measure upon the velocity of the piston, and its load; and also upon the size of the aperture, through which the steam issues from the boiler to the cylinder, compared with the elasticity of the steam in the boiler. In those engines the size of the aperture was that which is most generally used, and which is about one twenty-fifth of the area of the piston. I have, also, given the velocity of the piston, so that, in the

application of similar engines to practice, a comparison can be made.

To establish data for the performance of horses, I have given Tables of the work of horses upon three different lines of road, two of which may be considered as most favourable for the application of horses, where the whole of the goods are conveyed in one direction, and where the relative weights are similar to those given in the Table. The horses of Table I. were very heavy and powerful; and those of Table II. rather more so. The Horses of Table III. may be considered as moderately-sized horses.

The average performances of these horses fall below the expression of Mr. WATT, and reach beyond that of Mr. SMEATON; but,

as Mr. WATT'S expression was assumed more as a conventional standard for a horse's power, than the true measure of the energy which he is capable of exerting upon the load, perhaps those in the Table, being the result of long-continued practice, will be a more correct expression of his energy.

In the case of loco-motive engines, a sufficient number of Experiments are given, I trust, to elucidate both the laws which regulate their action, and, also, the extent of their performance and utility in the conveyance of goods upon Railroads. The uncertainty which exists, in general, respecting them, renders this extremely necessary; and, if I have been too prolix in the elucidation of their several modes of action, it has arisen from

a wish to satisfy public curiosity, and render the illustration of their properties clear and comprehensive.

CHAPTER IX.—Contains an outline of the comparative performance of the different available species of motive power in the conveyance of goods by Canals and Rail-roads. Tables have been given, explanatory of the weight of goods which horses can convey, at different rates of speed, upon Canals and upon Rail-roads; and, also, the weight which horses can convey on Canals, and which loco-motive engines can drag upon Rail-roads. The performance of the latter will, also, represent the effect with any other species of mechanical power on Rail-Roads, the energy of which corresponds with that assigned to the loco-motive engines.

These particulars, therefore, comprehend an outline of the matter contained in the work, which, I trust, will be found generally useful. Many subjects yet require elucidation and enquiry; in particular, Experiments are required to ascertain what part of the friction of carriages arises from the attrition upon the axles, and how much from the rolling of the wheels upon the rails; I intended to have made this the subject of early application to experiment; but, considering the necessity of the speedy appearance of the Work, to meet the public anxiety, I did not conceive it proper to delay the appearance of this work until I could obtain an opportunity of making these Experiments.

It will be seen, from the Experiments on the strength of rails, that considera-

ble deflexion was produced in the malleable iron-rails, when loaded with heavy weights. Considering the difference of opinion, as to their utility, compared with cast-iron, it is a subject of no trifling interest whether this bending tends, in any degree, to affect the resistance of carriages moved along the malleable iron-rails. I had prepared apparatus to determine this point, but have, for the present, been obliged to delay it, for the reasons previously stated.

KILLINGWORTH,
April, 1825.

A PRACTICAL TREATISE ON RAIL-ROADS.

CHAPTER I.

INTERNAL COMMUNICATION.

The Romans, it is probable, were the first who made any regular roads in Great Britain; for the purpose of facilitating the subjection of the inhabitants, and to secure a communication at all times between their armies occupying different quarters of the island; they formed what are now termed "military roads," which consisted of paths stretched across the country, from one place to another, and paved with large stones. These were generally of very considerable lengths, and made to pursue a straight line from station to station, thus affording a

hard, durable, and safe road, infinitely superior to the swampy, soft, and marshy paths, indiscriminately formed in all parts of the country, by its early inhabitants. Many of these roads are yet in existence in various places; and, as may be expected, from the purposes for which they were originally intended, they are very uneven and undulating. Their direction being from one station to another, which were generally placed upon the most elevated parts of the country, for the purpose of watching the motions of the enemy, these roads invariably avoid the more level parts of the country, and stretch from hill to hill.

For many centuries after the invasion of the island by the Romans, articles of trade were transported from one place to another, upon the backs of horses, which were called, "Pack-horses." Even so late as the middle of the last century, almost the whole land-carriage of Scotland, and of several parts of England, were conveyed on the backs of horses; and we find, at the present day, in most of the mountainous parts of Wales, and in the highlands of Scotland, the whole traffic carried on by the same mode of carriage.

The paved and hard roads of the Romans would afford a comparatively good track for horses, but as the inhabitants advanced in civi-

lization, and commerce required the transportation of bulky articles, this mode of conveyance would be inconvenient and inapplicable to the purpose. It is probable the next change of interior communication would be the introduction of sledges, where the articles to be conveyed was placed upon a square frame of wood, which was dragged along by the horse, and when the goods were very bulky the united effort of several horses could be then employed, which could not be done when it was laid upon their backs.

It is very uncertain at what period wheel-carriages were first introduced into Great Britain; the war-chariots of the ancient Britons formed a species of wheel-carriages, but it does not appear that at that period they were used for the purposes of conveying goods.

The Romans would, no doubt, introduce many of the Eastern articles of trade and of the arts; but such is the force of habit, that it appears, long after the invasion of the island by that people, the ancient inhabitants retained their native habits and customs.

By degrees, however, when civilization reached a higher degree of perfection, and commerce became more extended, the occurrence of articles of trade or comfort in the interior

districts of the country, would enforce the adoption of some mode of communication suitable to the advanced state of the arts and manufactures, and the use of wheel-carriages, where the weight that could be conveyed by a horse would be considerably greater than either what he could drag upon a sledge, or carry on his back, would proportionably extend the facility of internal traffic.

The next alteration, in interior communication, appears to have been the substitution of wooden Rail-ways, in place of the common or military roads, and these appear to have been first adopted in insulated districts, where the quantity of goods to be transported were considerable, and always over the same ground; but, as I intend tracing the history of this species of road, when I come to treat more particularly on that part of the work, I shall, in this place, not extend my remarks further than merely to notice it.

Canals, another kind of conveyance, and which is perhaps more extensively used in the conveyance of heavy goods, in most of the manufacturing countries, than any of the other species of internal communication, seems to have been the last introduced into Great Britain.

It appears, canals were used in Egypt long before the invasion of Great Britain by the Gauls—in China their introduction is said to have taken place at a very early date. Into Great Britain their introduction is comparatively recent. The attempt to form the Sanky Brook into a navigable canal, from the river Mersey to St. Helens in Lancashire, in 1755, appears to have been the first of the kind in England; and, since that period, they have been extended into almost every quarter of the island.

The benefits resulting to commerce from a cheap and expeditious communication between one place and another, for the conveyance of goods, being so very evident, needs no comment. The discussion has been carried on, and admitted by every political economist. In a manufacturing and commercial nation, the facility of transporting goods from the place where the raw material is produced, either to the consumer directly, or to the manufacturer, and from thence to the consumer, is not only a subject of essential importance, but next to the value of being able to manufacture cheap, and in a superior manner, enables us not only to carry on a successful competition with foreigners, but also to support a pre-

eminence in the market, and constitutes almost the whole support of commerce.

If the importance of facilitating commerce required illustration, every political economist, who has written on the subject, may be quoted in support of it. This does not, however, come within the limits which I have prescribed to myself in the present work. It has already been recently discussed in every shape in the different periodical publications, and also in some works written expressly for the purpose. The only question which I have undertaken is, to ascertain what species of internal communication presents those conditions in the greatest perfection.

Without anticipating, at this early stage of the work, conclusions which can only be obtained by the result of ulterior deductions, derived from detailed observations and experiments, it may be necessary briefly to state, that the competition seems almost wholly to rest between Rail-roads and Canals. It may be a question, in many cases, if Rail-roads can compete with existing common roads, in the economy and facility of the conveyance of goods and passengers; but whether Rail-roads are proposed to supersede canals or common roads, it is alike a subject of the deepest im-

portance to be fully acquainted with their nature, construction, and the extent of their utility, as a mode of internal communication.

The sudden change in the public opinion, respecting the preference of Rail-road to Canal conveyance, may excite surprise in the minds of many; on more attentive consideration, however, it will be seen to result from the natural course of events; and what, from the nature of the two modes, might have been anticipated; no doubt, the excess of capital in the country may have operated to accelerate the enquiry, but the real cause proceeds from the peculiar situation and condition of the two modes.

At the time of the introduction of canals into Great Britain, Rail-roads were in a state of relative insignificance, compared with the character which they at present assume; like other arts, they have been gradually and progressively improving; and, since the application of steam-power to drag the carriages upon them, they have attained such a feature of value, as to entitle them to the most serious attention of the public.

Canals, ever since their adoption, have undergone little or no change; some trivial improvements may have been effected in the manner of passing boats from one level to another, but,

in their general economy, they may have been said to remain stationary. Their nature almost prohibits the application of mechanical power to advantage, in the conveyance of goods upon them; and they have not, therefore, partaken of the benefits which other arts have derived from mechanical science.

The reverse of this is the case with Rail-roads; their nature admits of the almost unrestricted application of mechanical power upon them, and their utility has been correspondingly increased. No wonder, then, that canals, which at one time were unquestionably superior to Rail-roads in general economy, by remaining in a state of quiescence should, at some period or other, be surpassed by the latter, which has been daily and progressively improving, and perhaps that time is arrived. The human mind is generally averse and slow in adapting itself to the changes of circumstances, and though from this cause the competition in consequence might not have been so speedily brought into action, had not the present prosperity of the country induced capitalists to seek out every source of speculation, affording the least prospect of success. The natural course of events would, however, soon have developed the real situation of the two modes, in their respective relations to each other, and

though the time might have been prolonged when Rail-ways were brought into active competition with canals, yet its arrival would not be the less certain.

One might be led to suppose, that the question could readily be solved by an appeal to facts, or by the comparison of particular Canals with similar Rail-ways; but it is here I presume where the difficulty lies,—we cannot perhaps find Canals and Rail-ways whose external features are precisely the same; we are obliged, therefore, to have recourse to a comparison of general facts or principles peculiar to each mode, which again cannot be accomplished, unless we are fully and intimately acquainted with all the various properties and characteristics of each mode. The want of proper data was felt, and it is with a view of furnishing these, that the present work was undertaken; which, by a concise and at the same time comprehensive description of the construction, uses, and advantages of Rail-roads, together with an elucidation of the various principles of their action, the reader might be enabled to make a comparison with other modes of internal communication, and thus form a judgment of their relative value.

It is much to be regretted that a similar enquiry has not been made with respect to

canals; the present state of commerce requires that goods should be conveyed from place to place with the utmost rapidity, and, perhaps, we owe no small portion of mercantile prosperity to our facility of dispatch. The slow, tardy, and interrupted transit by canal navigation must, therefore, of necessity yield to other modes affording a more rapid means of conveyance, (especially when their relative economy is the same) unless they can be made to partake of the general activity, and additional celerity given to the boats conveyed upon them. Experiments, to ascertain the amount of resistance, at different rates of speed, would be therefore highly valuable; and, it is to be hoped, that such will be made on a practical scale upon some of the canals, to shew how far they are capable of affording a more speedy transit.

CHAPTER II.

HISTORY AND PROGRESS OF RAIL-ROADS.

It is very difficult to trace the precise date when Rail-ways were first introduced into Great Britain. When the traffic consisted of various articles, to be conveyed in numerous directions, the difficulty of forming a road suitable for all parties, and the expence of branching it off to all the different parts where the goods were to be carried, would operate to prevent the introduction of Rail-roads, as a species of general communication.

The more probable supposition is, that the adoption of these artificial roads first took place when the goods were of a certain description, and had to be conveyed to one place only; and when the quantity also was considerable. Continually passing along the same road, when perhaps the materials for upholding and keeping it in repair were expensive, might induce them to seek out some remedy; and, it is not unlikely, that the laying down of timber, in the worst parts of

the road, might tend to the introduction of wooden rails the whole distance. Such is the practice in Russia, and it appears to have been as ancient as civilization in that country.

At the coal-works in the neighbourhood of Newcastle-upon-Tyne, the expence of conveying the coals from the pits to the places where they were to be shipped by sea, would be very great. Down to the year 1600, the only mode appears to have been by carts, on the ordinary roads; and in some instances by "panniers" on horseback. A record in the books of one of the free companies in Newcastle, dated 1602, states, "That from tyme out of mynd yt hath been accustomed that all cole-waynes did usually carry and bring eight baulls of coles to all the staythes upon the ryver of Tyne, but of late several hath brought only, or scarce, seven baulls." The cost of transporting such a heavy article as coal along common roads, which may be supposed would not be of the best description, in carts containing seven or eight bolls, would operate very powerfully in accelerating the introduction of some improvement in the mode of conveyance, to lessen the expence.

In a work published at Newcastle, in the year 1649, by a Mr. Gray, called "A Chorographia," a survey of Newcastle-upon-Tyne,

the following account of the Coal Trade is given: "Many thousand people are employed in this trade of coales; many live by conveying them in waggons and waines to the river Tyne," &c. And in p. 31 of the same work, he states, "Some south gentlemen hath, upon great losse of benefit, come into this country to hazard their monies in coale pits. Master Beaumont, a gentleman of great ingenuity and rare parts, adventured into our mines with his £30,000, who brought with him many rare engines not known then in those parts, as the art to boore with iron rodds, to try the deepnesse and thicknesse of the Coale; rare engines to draw water out of the pits; waggons with one horse to carry down coales from the pits to the staythes to the river, &c.; within a few years, he consumed all his money, and rode home upon his light horse."

Considering that the carts employed in conveying the coals were, in 1602, called "waynes," and the carriages introduced by Master Beaumont "waggons;" and also, that ever since that period, the carriages employed upon Railroads have been designated by that name; we may infer, that the "waggon" of Mr. Beaumont was applied upon a Rail-way, and that he was the first to introduce them into the north.

The date of the introduction of Rail-ways, as a substitute for common roads, at Newcastle, would then take place between the years 1602 and 1649; probably a considerable time prior to the latter period, as we find Master Beaumont had at that time expended his £30,000.

Whether they were used in any other part of the country before this time or not, I have not had the means of ascertaining.

In 1676, they are thus described: "the manner of the carriage is by laying rails of timber from the colliery to the river, exactly straight and parallel; and bulky carts are made, with four rollers, fitting those rails, whereby the carriage is so easy, that one horse will draw down four or five chaldron of coals, and is an immense benefit to the coal-merchants."*

At that time, it is probable, the road would be of the simplest construction, consisting of single rails, fastened upon transverse sleepers, stretched across the road. The following description is given of them in Jaa's Voyages Metallurgiques, in 1765: (vol. I. p. 199.) "when the road has been traced, at six feet in breadth, and where the declivities are fixed, an excavation is made of the breadth of the said road, more or less

* Life of Lord Keeper North.

deep, according as the levelling of the ground requires. There are afterwards arranged, along the whole breadth of this excavation, pieces of oak wood, of the thickness of four, five, six, and even eight inches square: these are placed across, and at the distance of two or three feet from each other; these pieces need only be squared at their extremities; and upon these are fixed other pieces of wood, well squared and sawed, of about six or seven inches breadth by five in depth, with pegs of wood; these pieces are placed on each side of the road, along its whole length; they are commonly placed at four feet distance from each other, which forms the interior breadth of the road."

Fig 1.11 Plate I

Fig. I. *Plate* I. II. represent a plan and elevation of this kind of Rail-road, which was called the "single-way;" a a, a a, are the rails laid parallel to each other, upon the sleepers or transverse bearings, b b b b; the mode of fastening them together was by means of pins or pegs of wood, shewn at c c; holes being bored through the rail and sleepers, and the pins driven through the rail and about half way through the sleeper. The rails six feet long, and the sleepers about two feet apart. The ends of the rails meet upon the sleeper, as at c' c'; two pins being driven into the same sleeper fastens them down, and prevent them separating from each other.

This kind of Rail-road was very imperfect, and had many disadvantages, though probably

at first made of greater strength than necessary to support the weight, yet, by frequent use, the rails would soon become reduced in depth by the action of the wheels, and would break long before they were worn through. It would thus be necessary that the rails should be often renewed, and as the road required to be always of the same width, the bearing section of the sleeper, by the frequent perforation of the holes to fasten the sleeper down, would soon be rendered useless. Though much superior to the common roads, in point of economy and facility, yet the frequent renewal of the rails and sleeper would be attended with considerable expence, not only of time and labour, but also in the cost of the material.

The waste of timber thus occasioned, principally by the rail, when partly worn, being insufficient to support the weight of the carriages, and being therefore thrown away, would no doubt produce many attempts to remedy the inconvenience; and, it is not improbable but the addition of another rail upon the surface of that which rested immediately on the sleeper, was the next improvement, thus forming what is called the "double-way." The upper rail, or that subjected to the action of the wheels of the carriages, could then be almost completely worn away, without affecting, to a great de-

gree, the strength of that which supported the weight.

Fig. III. *Plate* I. is a representation of this form of rail; a a are the rails fastened down upon the cross sleepers b b b b, similar to those of the "single-way;" a′ a′ the rails laid upon the other, and firmly secured to them by wooden pins, in the same manner as the other rails are fastened to the sleepers. In the single-way, the joinings of the rails are necessarily upon a sleeper, as shewn at c′ c′; but in the double-way it is not so, for being fastened down upon the surface of the under rail, which in every part presents a proper bearing, they can be secured any where upon it; c″ c″ shews the joinings of the upper rail, which is midway between the sleepers, but which can be varied at pleasure. This prevents the under rail from being destroyed by the frequent perforation of the pin-holes in receiving the upper or wearing rail, and saves the waste of timber thus occasioned by use of the single-way.

The sleepers in this description of road were generally formed of young sapling, or strong branches of the oak, obtained by thinning the plantations, and were six feet long by five or six inches in thickness, and about the same breadth. At their first introduction, the under rail was of oak, and afterwards of fir, mostly six feet long, reaching across three sleepers, each two feet apart, and about five inches broad on the surface, by four or five inches in depth. The upper rail was of the same dimensions, and almost always made of beech or plane-tree.

The surface of the ground being formed pretty even, for about six feet in width, from the pits to the staiths, or the whole length of the intended Rail-road, or "waggon-way," as it was termed, the sleepers were then laid down two feet distant, and the under rail properly secured to them. The ashes, a material forming the surface of the ground, were then beat firmly against the under surface of the rail, which was thus strengthened and made more rigid. The upper rail was then placed upon the other, and firmly bound down by the pins or pegs of wood.

This combination had many very obvious advantages over the single rail, for, independent of the waste of timber before described, the destruction of the sleepers in the single rail by the feet of the draught-horses was considerable. The double rail, by increasing the height of the surface whereon the carriages travelled, allowed the inside of the road to be filled up with ashes or stone to the under side of the upper rail, and consequently above the level of the sleepers, which thus secured them from the action of the feet of the horses.

This description of Rail-road appears to have continued in use for a considerable period, and was extensively used at the collieries of Northumberland and Durham, and also in other

districts of Great Britain. The yielding nature of the material, especially when saturated with wet, would create very considerable resistance to the wheels, which, by sinking into and compressing the rails, would always form a rising surface, and thus impede the progressive motion of the carriages; still a horse was enabled to convey a greater weight along a Rail-road of this kind than upon a common road. At that time we find eight bolls of coals (equal to 17 cwt.) was the regular load for a horse with a cart or wain, upon the common roads; while, upon the Rail-road, the general load for one horse was nineteen bolls, or about 42 cwt.

The formation of the Rail-road would certainly be attended with considerable expence; but the advantages derived from the increased load, would soon compensate for this, and also for an increase of expence in keeping up the rails. In general, the collieries were situated at a much higher level than the depôt or places to which the coals were to be conveyed; consequently, the Rail-roads would mostly descend in the direction of the load:—except levelling down abrupt undulations, little care was taken to make the road with an uniform descent. For many years after the introduction of the wooden Rail-way, waggons containing nineteen bolls,

or about 42 cwt. was the universal load attached to a horse, and the road was levelled accordingly, the only desideratum being to enable a horse to convey that quantity.

In some parts of the road, where occasional acclivities occurred which could not be levelled, or where sudden windings of the road were obliged to be made, thin plates of wrought iron were laid upon the surface of the Rails, and fastened down with common nails, to diminish the resistance opposed to the wheels, and equalize the draught of the horse. This, no doubt, would be found a great improvement, not only in diminishing the friction, but also in preventing the Rails from wearing. Yet I do not find the use of them much extended beyond the above-named instances; probably, from the difficulty of keeping the plates fast upon the Rails, as the nails, by the elasticity of the wood, would be constantly working loose, and occasioning a continual expence in keeping them right. Upon the whole, however, the use of such plates would, in many cases, be attended with considerable benefit, and might, had they not been superseded by the introduction of a different kind of road, have been much improved.

About this period, in all the extensive mining districts, we find canals the only system of internal

communication for general traffic: and these, by the indefatigable and enterprising genius of Brindley, assisted by other eminent engineers, being carried into every quarter of the island. Rail-ways were thus confined to a very limited and subordinate sphere of action—to short distances, or over uneven or highly-inclined ground, where the number of locks precluded the use of canals. The attention of all scientific men being thus absorbed in another species of conveyance—the subject of Rail-ways would be little attended to, and this, perhaps, will account for the slow progress made in the improvement of them, compared with that of the other mode of conveyance—accordingly, we find a long period intervene after the introduction of wooden Rail-ways, beyond the application of any other material. before

The diminution of friction, by the plates of malleable iron, upon the wooden rails, is very likely to have suggested the propriety of using that material entirely; but I cannot find that wrought-iron was any where used alone until within a very recent period.

The next improvement, in the order of time, and also of importance, appears to have been the use of cast-iron, as a substitute for the wooden rails; and, like the introduction of Rail-ways, though comparatively of a very

modern date, the precise period of their first adoption is involved in mystery.

A late anonymous author says, without advancing his authority, "that, in 1738, cast-iron rails were first substituted for wooden ones; but, owing to the old waggons continuing to be employed, which were of too much weight for the cast-iron, they did not completely succeed in the first attempt. However, about 1768, a simple contrivance was attempted, which was to make a number of smaller waggons, and link them together, and by thus diffusing the weight of one large waggon into many, the principal cause of the failure in the first instance was removed, because the weight was more divided upon the iron." (Trans. Highland Society, vol. VI. p. 7.) It is somewhat singular, when the failure of the attempt to introduce cast-iron arose from the want of strength in the rails, that it should require thirty years to discover that, with a lighter load, they could be made to answer.

Mr. R. Stephenson, whose enquiries into Rail-road conveyance have been pretty extensive, states, "I some years since visited the great iron-works of Colebrook-dale, in Shropshire, where cast-iron was indisputably first applied to the construction of bridges, and, according to the information which I have been

able to obtain, it was here also that Rail-ways of that material were first constructed. It appears, from the books of this extensive and long-established Company, that between five and six tons of rails were cast on the 13th of November, 1767, as an experiment, on the suggestion of Mr. Reynolds, one of the partners."

I think there is every reason to believe that the latter is the more probable term of the first introduction of cast-iron rails. In the first place, iron *wheels* were not used until about 1753, and at that time only very partially; it was not until several years after, that they came into general use—so long, therefore, as wooden wheels were made use of, we may suppose cast-iron rails had not been invented.

Mr. Carr, in his Coal Viewer and Engine Builder, published in 1797, says, "the making and use of iron Rail-roads were the first of my inventions, and were introduced at the Sheffield colliery, about twenty-one years ago." This would make the date of their introduction about 1776, which is subsequent to that of Colebrookdale.

Fig. IV. *Plate* I. Represents the form of Mr. Carr's cast-iron rails, which were used under-ground at the Duke of Norfolk's colliery, near Sheffield; a a a a, are the rails, which were six feet long, and in the form as shewn in *Fig.*

V.; near each end of the rail small holes were cast, through which a nail was driven into the sleepers, which was of the same description as those of the wooden rails, *Fig.* II., and shewn by the dotted lines in *Fig.* IV.; at the joinings of the rail at c c c c, they were merely laid against each other at the ends, and nailed down to the sleeper, the intermediate sleepers having only one nailing; *Fig.* V. shews a section of this form of rail; a b, the horizontal bearing in which the wheel travelled; and b c, the upright ledge or projection to prevent the wheels from running off the road.

Various forms of this rail, which is called the "Plate Rail," appear to have been used with either wooden sleepers stretched across the whole breadth of the Rail-road, or short square wooden sleepers, as shewn in *Fig.* IV., on which the rails were nailed. In the year 1800, we are told that Mr. Benjamin Outram, an engineer, in adopting this rail on the public Railway at Little Eton, in Derbyshire, introduced stone props instead of timber, for supporting the ends and joinings of the rails.

Mr. Outram, however, was not the first who made use of stone supports, as the late Mr. Barns employed them in forming the first iron Rail-road which was laid down in the neighbourhood of Newcastle-upon-Tyne, viz. from Lawson main colliery to the river, in 1797.

This kind of rail has undergone many alterations in form since it first came into use.

Fig. VI. *Plate* I. is a ground plan; *Fig.* VII, a side

view; and *Fig*. VIII. a section of the most improved form of this kind of rail;—c c c c are the rails, four feet long, placed upon stone supports, about a foot square, and eight inches deep, as shewn in *Figs*. VI. and VII.; at the ends of each rail, when they are laid against each other on the stone support, a small square piece is cut or left out in casting the metal, increasing in size upwards, so that, when the two ends are laid together, these two holes form a sort of square hole through the ends of the rail, narrowing downwards; a perfectly level and horizontal groove is then made on the top of the stone, and the rail imbedded in it; a hole, corresponding with the square hole of the rails, is drilled into the stone, about half the depth; an iron pin is then driven into the stone through the hole in the rails, which having a bevilled head fastens them down to the stone, one half of the pin securing one rail, and the other half the adjoining rail, as shewn in the drawing; these nails are generally from three to four feet long.

Fig. VIII. is a section of the rail; a d, the bottom or wheel-track, about four inches wide and an inch thick, which is made quite level; d e, the flange or upright ledge to keep the wheel upon the part a d of the rail, and a f a, the flange projecting downwards to strengthen the rail; the upright flange is the same height throughout the whole length of the rail, as shewn in *Fig*. VII. being no higher than is necessary to secure the wheel upon the proper track, and which of course requires no greater depth in one part than another, and the height adding to the friction of the carriage-wheels, it will necessarily be made as low as possible; hence we find it never exceeding three inches. This restriction in the height of the upright edge limits the form of the section, and renders it not that of the greatest strength; the resistance to fracture being as the breadth and square of the depth, the horizontal part a d of the rail, while it adds to the cost,

does not in the same degree add to the strength; the upright section d i, being the only part in that position which presents the strongest form of section; this, however, as previously stated, being limited in height or downright projection, has been cast upon the opposite side of the buoying section of the rail, shewn by a f, *Fig.* VIII. and a f a, *Fig.* VII., the form of this, as shewn in the latter figure, is such as to secure equal strength in every part of the rail, being deeper in the middle, f, and tapering away in a parabolic or semi-elliptic form, in both directions, to the ends of the rail.

This form of rail, with very trifling modifications, constitutes the most modern plate rail; until very lately they were universally made of cast-iron; but, about a year ago, some were formed of wrought-iron; the latter have as yet, however, been very partially used.

Soon after the introduction of cast-iron rails, a form of rail, called the "Edge Rail," was brought into use. Mr. W. Jessop, in 1789, formed the public Rail-road at Loughborough with this kind of rail; the upper surface of which was of an elliptical figure, with flanges upon the wheels to guide them upon the tracts of the road.

In the wooden Rail-ways, the upper rails were convex on the surface, and upon one side of the periphery of the wheels a flange projected downwards about an inch, which served to keep the wheels upon the rail; when the plate-rail was introduced, the form of the peri-

phery of the wheel would be altered, being made quite flat and of less breadth; and, the rim of wheel, for the edge-rail, was again brought back to the same form as that for the wooden Rail-road.

Fig. IX. *Plate* I. Represents an elevation or side-view of the edge-rail, as mostly used in late years, which consists of a bar of cast-iron, from three to four feet long, and about one-half or three-quarters of an inch thick, swelling out at the upper part to two or two inches and half broad, for the wheel to run upon, and placed upright, within a sort of chair, upon the stem supports. These rails, when first used, were not secured upon the stone or wooden sleeper by a separate chair or pedestal, but had a flat bearing projecting outwards, on each side, at the end of the rail, through which were square holes for the pins or nails to pass, that fastened them to the sleepers.

It is evident that this form of rail combines the greatest strength with the least expenditure of material; for, being placed upright, they present the greatest depth in the direction of the stress or strain upon them. The form first used was nearly a parallelogram. *Fig.* III. *Plate* II. will show a section of those at present used, the breadth of the upper surface, *a*, is about two inches and a half; after keeping this breadth a little way down, as shewn in the drawing, they gradually diminished to three-quarters, tapering down to half an inch, near the bottom at *c*; this was the section of them for a long period, but

they are now made again to swell out at the lowest extremity, as shewn at *c, b*. The lateral thickness of the rail is generally the same throughout the whole length. The depth, as shewn in the drawing, is varied according to the distance from the supports; and of that form which is intended to present the same strength, wherever the wheels of the carriage may be placed upon them.

The form of the chairs will be readily understood, on referring to the drawings; they are fixed in a sort of bed, on the top of the stone, by wooden pins; the base, on which the rail rests, being quite flat and horizontal, two upright ledges are cast perpendicular to the base of the chair, forming a sort of parallel cavity, into which the ends of the rails are laid; holes are made near the end of the rails, corresponding to similar holes cast in the chairs, through which pins are driven. These fasten them to each other; and prevent the ends of the rails from starting out of their places, when the carriages come upon them; and the sides or cheeks of the chair prevent them from moving laterally or sideways.

Fig. VII. *Plate* II. Shews the mode of joining on a large scale.

When the surface of the ground is made level, the stone supports properly laid down,

and the rails fastened neatly together, they will, with the exception of the joinings, at intervals of every three or four feet, according to the length of the rails, which will, if the road be laid down with tolerable accuracy, and the ends of the rails squared, be scarcely visible, form a continued uniform line. The carriage-wheels, in rolling along such, can meet with little obstruction, and the friction or resistance upon such a road is comparatively trifling.

The base of the stone should be formed quite parallel with the bed of the chair, and consequently square with the line of the rails: the chair should also be placed exactly in the centre of the stone. The surface of the ground, wherever the stone rests, should be made firm and hard, to secure the parallelism of the base of the stone with the line of the rails; otherwise, when the weight comes upon them, the parallelism of the rails will be soon destroyed.

I have before stated, that the rails are fastened to the chair, and also kept at the proper distance from each other, by two pins passing through the chair, and through holes near the ends of the rail. In the chairs these holes are situated in a line or parallel with the base of the chair on which the rail rests. In the rails they are at equal distances from

the top, or bearing surface; the rails, therefore, either rest upon the flat base of the chair, or upon the pins. When the pins do not fill the holes, the rails will of course rest upon the chair; but, if the pins are driven tightly through the holes of the rails, they will necessarily be supported by the pins; and, in either case, the parallelism of the surface of the rails will depend upon the parallelism of the base of the chair with the line of the road.

If the surface of the ground on which the stone rests be not of the same degree of firmness throughout, or the chair be not placed precisely in the centre of, and parallel with, the bearing section of the stone, the weight of the carriages passing along the rail will displace the stones, by moving them from their parallelism with the line of the road, and throwing them down on one side into the position represented at *c′ c′*, *Fig.* IX. *Plate* I. This necessarily depresses one side of the base of the chair, and also one of the pins, below the other, and consequently depresses the end of that rail fastened to it below the line of the other, as shewn at *d′ d′*. And this derangement of the rails will take place whenever the line of the base of the stone does not correspond with the line of the road; and will be in proportion to the angle the one forms with the other.

When the nature of the ground on which the stones rest is considered, as also the difficulty of always compelling the workman to bed the chair precisely in the centre and parallel with the base of the stone, and of obtaining stones of the proper form, it will not be wondered that such a derangement frequently takes place; accordingly, we find in practice, that it is extremely difficult to keep the rails in proper order, from the liability of the stones thus to fall down, and depress the one end of the rail considerably below that of the other, and in some cases so much so as to form a rising surface of considerable height, like that represented in the drawing; which is by no means a magnified representation of the derangement which often occurs.

The evil arising from such projections need scarcely be stated; the shocks to the carriage-wheels, the obstruction to the moving power, and the injury to the carriages and the rails themselves, must be so very apparent, as to need no illustration; and the necessity of remedying such a defect so very obvious, as to strike every one at all conversant with the subject in the most forcible manner.

Various plans of chairs and of rails have been devised, by different persons, to obviate

this imperfection, and, in 1816, a patent was obtained for a form of rail and chair, by WM. LOSH, Esq. of Walton, and Mr. GEORGE STEPHENSON, of Killingworth, which appears to be the best form in use at present, and to obviate, in a great degree, the evil arising from such a defect.

Fig. I. *Plate* II. Is a side-view of their patent rail; shewing the rails *a a a a* connected with each other, fixed in chairs, and placed upon stone supports, similar to those for the other rails; the joinings of the rails with each other are accomplished by means of what is denominated a half-lap, shewn at *e e e e*, *Fig.* II. the side of the rails being bevelled away near the ends for about two inches and half; so that, when the two bevelled ends are laid against each other, they only form the same breadth of surface as the top of the rail in other parts; one pin-hole therefore passes through the two ends, and a single hole being made in the chair, a strong iron pin is driven through the whole, which keeps the ends of the rails from separating; *d d d d d*, *Fig.* II. show a plan of the chairs, and B, *Fig.* VII. a side-view on a larger scale; the half-lap extends the length of the chair 1-2, *g* shows the pin-hole, which passes through both rails; the base of the chair on which the rail rests, is shewn by the dotted line *h*, the bearing or under surface of the rail being quite straight and parallel with the top of the rail. The patentees state, " our objects are, first, to fix both the ends of the rails, or separate pieces of which the ways are formed, immoveable, in or upon the chairs or props by which they are supported. Secondly, to place them in such a manner that the end of any one rail shall not project above, or fall below, the correspondent end of that with which it is

in contact, or with which it is joined. Thirdly, to form the joinings of the rail with the pedestals or props which support them, in such a manner, that if these props should vary from their perpendicular position in the line of the way, (which in other Rail-ways is often the case) the joinings of the rail with each other would remain as before such variation, and so that the rails should bear upon the props as firmly as before. And the rails being applied to each other by what is called a half-lap, and the pin or bolt of which fixes them to each other, and to the chair in which they are inserted, is made to fit exactly a hole which is drilled through the chair, and both ends of the rails, at such a height as to allow both ends of the rail to bear on the chair; and the bearance being the apex of a curve, they bear at the same point. Thus the end of one rail canno rise above that of the adjoining one; for, although the chair may move on the pin in the direction of the line of the road, yet the rails will still rest upon the curved surface of the bearing without moving."

This plan of joining the rails is evidently a great improvement over the common mode and has been almost universally adopted on all new lines of road; the blows and shocks to which the carriage-wheels were exposed in the other, has been almost entirely exterminated in this plan; and the benefit is not confined to the carriages alone, for the reaction of those shocks were often liable to break the rails in return. The difference is very sensible in passing along the two kinds of rails in carriages; on the one you travel smoothly along, with scarcely the

least tremor of the carriage; but immediately that you come upon the other, a continuance of jolts and shakes is felt, as the carriage-wheels successively pass over each joint. The injury caused to the carriages, though not immediately felt, yet, by frequent repetition, must eventually tend to shake them in pieces; the wear of the wheels of the carriages also, by the blows, will be considerable.

Nothing, however, is of greater importance, in estimating the benefits obtained by this mode of fixing the rails, than the diminution of the resistance opposed to the wheels of the carriages. Many practical examples could be adduced where the difference has been found to be very great indeed; the projections acting as successive obstacles to retard the progressive motion of the wheels, and which were to be surmounted at every joining.

Various modifications of this mode of fixing the rails have been attempted; to describe the whole of them would be impossible.

C and D, *Fig.* VII. *Plate* II. Shew two which are worth notice. In the first, the ends of the rails are square, similar to the old rails; at each end a semicircular indentation is made, equal in diameter to the pin-hole in the chair; when the ends of the two rails are laid together, a circular hole is formed, through which the pin is driven, passing through the chair on each side of the rail; the pin has no effect in fastening them together in the direction of their length, but

as when they are laid down they cannot separate in that direction, the pin will prevent their rising up, being the only way in which they have a tendency to separate. D represents a mode of preventing the rails from rising up without a pin; the ends of the rails are cast in the form shewn by the dotted lines, one end having a convex projection, which fits into a concave indentation cast in the end of the adjoining rail; and the sides or cheeks of the chair keeping the ends always opposite each other, the projecting piece keeps the ends of the rails in the same place.

In all the chairs of these forms which I have seen, the base whereon the rails rested were flat. If the first rested or hung upon the pin only, the stone might then be depressed considerably, without materially affecting the joining, the stone turning upon the pin as a pivot or centre; but if the rails rest upon the flat base of the chair, this cannot take place without subjecting the pin to a considerable strain, and causing it to work itself loose.

Something of this takes place, though not to so great an extent, in the Patent mode of Messrs. Losh and Stephenson, for if the pin fill the hole through the end of the rails and chain, the stone can only move upon the pin as a centre. If the rail then rest upon the apex of the curve, and the stone becomes depressed on one side, the apex bearing of the chair is not at liberty to move round the pin as a centre, being prevented by the flat surface of the under

side of the rail, forming a tangent to the arc it would describe; the pin, in such cases, must therefore yield to the action of the weight; and, consequently, have a tendency similar to the rail above described; this, however, is the only imperfection it has, for the overlap effectually prevents the distortion of the joinings of the rails; whereas, in the other modes, the ends are liable to rise and get out of the same plane.

Effectually to preserve the continuity of the rail with ease and freedom, the stone should be capable of moving round, or assuming any degree of inclination, to the line of the road that might occur in practice, without straining either the pin or distorting the ends of the rails: to effect this, if the pin be made the centre of motion, the under side of the rail should be a portion of the circumference of a circle, formed from the pin as a centre;—the base of the chair could then be either the apex of a curve, or a circular cavity corresponding with the exterior semi-circular surface of the rail. The stone might then be depressed on either side, without straining the pin or deranging the joints; or we might otherwise make the bearance of the rail upon the chair or pedestal the centre of motion; in such case, the pin-hole should be a circular slit or open-

ing, formed from the bearing upon the chain as a centre. The pin being made exactly to fit this cavity in a perpendicular direction, would prevent the rails from starting upwards out of their proper position, and the semicircular form would allow it to run longitudinally—when the stone then became depressed towards one side, the chair could move round without injuring the pin, or deranging the joints of the rails.—The form of chair *d*, *Fig.* VII., if the bearance had been upon a point instead of a flat surface, nearly partakes of these properties without a pin, for then the chair would move upon such point without affecting the joinings of the rails; but, in that case, the ends of the rails should form an over-lap; or, if the rails rested upon the top of the chair, and the top was of a circular form, described from the middle of the chair as a centre, the bearance of the rail on the middle of the chair being the apex of a curve, the same effect would take place.

Innumerable forms of joinings might be devised, every one of which might, in some measure, effect the purpose intended. The essential consideration being to secure a continued and permanent parallelism in the rails, under every derangement that may take place of the supports on which they rest, it is not

enough that the bearing be such, that the rails are all in the same plane when the stones on which they rest are in good order, or in their proper position, parallel with the line of the road: the parallelism of the rails should be preserved, when, by the yielding of the ground, or from any other cause, the stones are displaced from their proper position, and they are made to form a considerable angle with the line of the road. It would not have been necessary to have been thus diffuse on this point, had I not found that several, even of the most modern forms of chair, were evidently formed contrary to this principle: — many, with a view of causing the mode of joining to keep the support or stone in its proper position, rather than allowing it to adapt itself to the unavoidable yielding of the ground on which it rests, or parallel with the rail: but the least consideration will evince the futility of this, especially when the yielding of the ground causes the stone to rest entirely on one side; it will at once be seen, that when the carriages come upon the rails, something must yield and give way, by the great strain thrown upon the fastening from the oblique action of the weight.

About twenty years ago, malleable iron rails were tried at Wallbottle Colliery, near

Newcastle-upon-Tyne, by Mr. C. Nixon; the rails were square bars, two feet in length; they were joined together by a half lap joint, with one pin, one end of the rail projecting beyond the end of the adjoining one two or three inches. Their use was not at that time extended; the narrowness of their surface cut the periphery of the wheels, and they were superseded by the cast-iron rails with a broader surface.

Mr. R. Stephenson states, that malleable iron rails were first introduced about the year 1815, at Lord Carlisle's Coal-works, on Tindale Fell, Cumberland; and, as above stated, they were used long before that period; he must also have been misled as to their introduction at Tindale Fell, as, according to the statement of Mr. Thompson, the present agent, they were laid down on that Rail-road in 1808. Since that period, they have been partially used in other places, but not to any extent, until very recently.

In October, 1820, Mr. John Birkinshaw, of the Bedlington Iron-works, obtained a patent for an improvement in the form of malleable iron rails. The shape of the malleable iron rails previously used, were bars from two to three feet long, and one to two inches square; but either the narrowness of the surface

produced such injury to the wheels, or by increasing their breadth the expence became so great, as to make their cost greater than cast-iron, which consequently was preferred.

It was to remedy these defects in the malleable form, and at the same time secure the same strength as the cast-iron, that MR. BIRKINSHAW made his rails in the form of prisms, or similar in shape to the cast-iron. *Fig*. IV. *Plate* II. shows a side-view of this kind of rail; *Fig*. V. a plan; and *Fig*. VI. a section of the same rail, cut through the middle.

These rails are formed by passing bars of iron, when red-hot, through rollers, with indentations or grooves in their peripheries, corresponding to the intended shape of the rails; the rails thus formed present the same surface to the bearing of the wheels, and their depths being regulated according to the distance from the point of bearing, they also present the strongest form of section with the least material. The mode of rolling these bars on rails, and giving them the gradual swell towards the middle, not only in the horizontal section, but also a lateral swell 1.2 commencing at each support, gradually increasing to the centre, and then again tapering away towards the point of support, are very injurious. They are gene-

rally formed in lengths of twelve to fifteen feet, as represented in the drawing, and subdivided into bearing lengths of three feet each; but the patentee adds, in his specification, "the respective rails may be made of considerable length, (eighteen feet I should recommend) by which the inconvenience of numerous joints is reduced; and, consequently, the shocks or jolts to which the carriages are subject from passing over the joints, (very much to the injury of the machinery) are also diminished. And in order still further to remedy the evil arising from the joints of the rail-road, I propose to weld the ends of the bars together as they are laid down, so as to form a considerable length of iron rail in one piece."

The joinings of these rails, as shewn in *Fig.* V. are square at the ends, similar to the old rails; but I see no great difficulty in forming them with a half lap, and thus giving them the same superiority of joining as possessed by the improved cast-iron rails.

These two kinds of rails, represented in the *Figs.* I. and IV. are the best at present in use, and each have their advocates. Without attempting to decide upon the merits of each, I have, as the subject is of considerable importance, extracted out of some published reports the opinion of some engineers, which may not be uninteresting to the reader.

Mr. Chapman, in his report on the Newcastle and Carlisle communication, states, "the Railway may either be formed of cast-iron or malleable iron. The latter may be somewhat less expensive, and has been found eligible in rolley-ways below ground, in which the weight on each wheel is not considerable; but, above ground, with heavy waggons, their utility, or rather their duration, is not likely to be so great as rails of cast-iron of due strength, because with heavy carriages, and case-hardened wheels (which are much in use except for locomotive engines, as it would diminish their adhesion to the way,) the following effect is produced from the softness of malleable iron, and the rails formed of it being drawn out between rollers, and consequently fibrous, viz.:—the great weight on these wheels, rolling on those ways, expands their upper surface, and at length causes it to separate in thin laminæ. The injury from oxydation is comparatively small." *

This report caused a reply from Mr. Longridge, one of the Proprietors of the Bedlington Iron-works, defending the utility of those rails, who produced a letter from Mr. Thompson, Lord Carlisle's agent at Tindale Fell, stating

* Chapman's Report on the Communication between Newcastle and Carlisle.

that the malleable iron rails, which had been laid down there for sixteen years, had no appearance of lamination. "The whole of the wrought-iron," says he, "which has been used from twelve to sixteen years, appears to be very little worse. The cast-iron is certainly much worse, and subject to considerable breakage, although the rails are about double the weight of the malleable iron rails. The waggons used to carry near a Newcastle chaldron, viz. 53 cwt."—(*Newcastle Courant, Dec.* 18, 1824.)

Mr. R. STEVENSON, Engineer of Edinburgh, states, regarding the description of materials to be used in the formation of rail-ways, "I have no hesitation in giving a decided preference to malleable iron, formed into bars of from twelve to twenty feet in length, with flat sides, and parallel edges, or in the simple state in which they commonly come from the rolling mills of the manufacturer." — (*Transactions Highland Society*, vol. 6, p. 139.)

Mr. G. STEPHENSON, of Newcastle, the patentee of the cast-iron improved rail, has allowed me to insert a copy of a report made by him on the subject. "The great object in the construction of a Rail-road is, that the materials shall be such as to allow the greatest quantity of work to be done at the least possible expenditure; and that the materials also be of the

most durable nature. In my opinion, Birkinshaw's patent wrought-iron rail possesses those advantages in a higher degree than any other. It is evident that such rails can at present be made cheaper than those that are cast, as the former require to be only half the weight of the latter, to afford the same security to the carriages passing over them, while the price of the one material is by no means double that of the other. Wrought-iron rails, of the same expence, admit of a greater variety in the performance of the work, and employment of the power upon them, as the speed of the carriages may be increased to a very high velocity without any risk of breaking the rails; their toughness rendering them less liable to fracture from an impulsive force, or a sudden jerk. To have the same advantages in this respect, the cast-iron rails would require to be of enormous weight, increasing, of course, the original cost.

"From their construction, the malleable iron rails are much more easily kept in order. One bar is made long enough to extend over several blocks; hence there are fewer joints or joinings, and the blocks and pedestals assist in keeping each other in their proper places.

"On this account, also, carriages will pass

along such rails more smoothly than they can do on those that are of cast-iron.

"The malleable iron rails are more constant and regular in their decay, by the contact and pressure of the wheel; but they will, on the whole, last longer than cast-iron rails. It has been said by some engineers, that the wrought-iron exfoliates, or separates, in their laminæ, on that part which is exposed to the pressure of the wheel. This I pointedly deny, as I have closely examined rails which have been in use for many years, with a heavy tonnage passing along them, and on no part are such exfoliations to be seen. Pressure alone will be more destructive to the cohesive texture of cast-iron than to that of wrought-iron. The true elasticity of cast-iron is greater than that of malleable iron, *i. e.* the former can, by a distending power, be drawn through a greater space, without permanent alteration of the form; but it admits of very little change of form without producing total fracture. Malleable iron, however, is susceptible of a very great change of form, without diminution of its cohesive power; the difference is yet more remarkable, when the two substances are exposed to pressure, for a force which, in consequence of its crystalline texture, would crumble down the cast-iron, would merely extend

or flatten the other, and thus increase its power to resist the pressure. We may say, then, that the property of being extensible, or malleable, destroys the possibility of exfoliation as long as the substance remains unchanged by chemical agency. A remarkable difference, as to uniformity of condition or texture in the two bodies, produces a corresponding want of uniformity in the effects of the rubbing or friction of the wheel. All the particles of malleable iron, whether internal or superficial, resist separation from the adjoining particles with nearly equal forces. Cast-iron, however, as is the case with other bodies of similar formation, is both harder and tougher in the exterior part of a bar, than it is in the interior. This, doubtless, arises from the more rapid cooling of the exterior. The consequence is, that when the upper surface of a cast-iron rail is ground away by the friction of the wheel, the decay becomes very rapid.

"The effects of the atmosphere in the two cases are not so different as to be of much moment. On no malleable iron Rail-way has oxydegerent, or rusting, taken to any important extent.

"I am inclined to think that this effect is prevented, on the bearing surfaces of much used Rail-ways, by the pressure upon them. To

account for their extraordinary freedom from rust, it is almost necessary to suppose, that some diminution takes place of the chemical affinity of the iron for the oxygen or carbonic acid. The continual smoothness in which they are kept, by the contact of the wheels, has the usual effect of polish, in presenting to the destroying influence a smaller surface to act upon. The black oxide, or crust, which always remains upon rolled iron, appears to act as a defence against the oxydizing power of the atmosphere, or water. This is the reason why the rail does not rust on its sides."

One phenomenon in the difference, in the tendency to rust, between wrought-iron laid down as rails, and subjected to continual motion by the passage of the carriage over them, and bars of the same material, either standing upright or laid down, without being used at all, is very extraordinary.

A Rail-way bar of wrought-iron, laid carelessly upon the ground, alongside of one in the Rail-way in use, show the effects of rusting in a very distinct manner. The latter will be continually throwing off scales of oxydated iron, while the former is scarcely at all affected.

The first cast-iron rails were by far too weak. Scarcely any of the rails laid down twenty years ago are in existence; this is partly owing to

the increased weight now carried upon the rails, and also the mistaken policy in the saving by the lightness of rails, and the cost compared with the wooden way.

It seems necessary that the rails should be made considerably stronger than merely to support the weight they have to carry. The blows they are subjected to, from the unevenness of the road, transferring the weight alternately from one side of the carriage to the other—and the side-shocks from projections upon, or on, the sides of the rails, all have a tendency to snap the rails in two, or bend the malleable iron.

Upon public, or other Rail-roads, when the carriages move with great velocity, the breakage of the rails should be carefully guarded against, as the most dangerous consequences might ensue, by such breaks setting the carriages off the road; and the velocity with which the carriages travel, would render it difficult, perhaps, to stop them in time before an accident happened.

Having thus described, and pointed out some of the properties of the different rails at present used, both of cast and malleable iron, it may be necessary to mention a plan of rail composed of both these kinds of iron. Mr. John Hawks, of Gateshead, in 1817, obtained a patent for a

rail, which he stated, in his specification, "to be a compound of malleable and cast-iron, so connected, as to be stronger than if made of either alone," and which consisted of a bar of malleable iron formed into the proper shape of the under part of the rail below, the flat part on which the carriages run; the upper side of the malleable iron was then made rough and uneven, or dovetailed, and the cast-iron top run upon it in a state of fusion, thus forming the rail for about three quarters of an inch down of cast-iron, and the remainder of malleable iron. In all rails, or bars of iron, supported upon the ends, and loaded in the middle, the under part is in a state of tension, and the upper part subjected to compression. It is known that malleable iron resists tension with greater force than cast-iron, and, on the contrary, that cast-iron resists compression in a greater degree than malleable iron, by pressing the upper part of the rail, or that subjected to compression, of cast-iron, and the under part which is exposed to a state of tension of malleable iron. Mr. Hawks expected to secure greater strength in his combination, than if formed of either material separately, and also to present the hardest material to the wheels of the carriages. The great care required, in accomplishing a proper and firm joining of the two, rendered

the making of them very difficult, the wrought-iron requiring to be entirely free from the least damp, otherwise the soundness of the cast-iron was injured; this, added to the circumstance of the malleable iron part being made too weak, and by yielding to the weight, caused the cast-iron to crack, and eventually work loose, prevented, I believe, the extension of their use, though, if properly manufactured, they might have become useful.

Various other kinds of rails, both of cast and malleable iron, have been used; but it would be swelling the work to, perhaps, an unnecessary size, to attempt the description of them. The two kinds figured in the drawings constitute those most extensively used in the Northumberland and Durham Rail-ways, where certainly the experience of their utility has been very considerable, from their extensive use in the application to the conveyance of goods.

It seems to me a matter of great astonishment, that the plate-rails have yet many advocates; and what seems more unaccountable, is the mistaken notion of the friction being less upon them than upon the edge-rail. I should have thought that the number of Rail-ways of both kinds now in existence, would have afforded sufficient opportunity of ascertaining this fact, without having recourse to surmise or opinion.

Sufficient proof will be adduced hereafter, in the account of experiments on friction, to show the absurdity of retaining such a supposition, which is also apparent from the nature of the action of the carriage-wheels upon the two rails. Certainly, if the wheels in the plate-rails be equal in breadth to the surface of the rails in the other, and the former always rolls along the rail without rubbing against the sides of it, more than the ledge of the wheel rubs against the side of the edge-rail, then the friction in the two cases might be equal; but herein lies the mistake, the rubbing of the wheels against the plate-rails is considerably greater than the rubbing of the wheels against the sides of the edge-rails. The height of the ledges of the rails in the plate-rail, is greater than the depth of the ledge upon the wheels in the edge-rail, and consequently the friction by those proportions will be in the same proportion. The general height of the ledge of the flat rail is three inches, and that of the wheels of the other never exceeding one inch, and as the tendency to rub against the ledge is the same in each, nay, as will be hereafter shewn, greater in the flat than in the edge-rail, the friction will therefore be as the height of the ledges. This is supposing the rails equally free from obstruction, or

extraneous matter, affecting the free rolling of the wheels upon them; but any person will see that the form of the plate-rails necessarily causes them to be more subject to the pressure of such obstruction than the edge-rail, the one forming a sort of receptacle for the dust, dirt, and other substances falling upon them; while the other, from its narrow surface, and elevated position, tends to throw off any extraneous matter which may accidentally fall upon it. Mr. Palmer, in his description of a patent Railway, gives a very interesting experiment on the obstruction caused to the carriages by the dust upon the plate-rails, which I shall take the liberty of inserting: he states, "I made an experiment on a branch of the Cheltenham team-road (which was nearly new and in good condition) with a view to ascertain the difference of resistance occasioned by dust lying upon the rails. The carriage and its load weighed 5264 lbs.; the rails being swept clean, the resistance was thirty-six pounds; the rails being slightly covered with dust, the resistance was forty-three pounds. Consequently, the difference of resistance to that weight was seven pounds, being upwards of one-fifth increase."

The tendency of the edge-rail to form a rut or groove on the periphery of the wheels, and thus to increase the friction, was for a long

period a motive for preferring the other; and this wear was considerable at first, owing to the narrow surface of the rails; afterwards, when the bearing of the rails was made greater, and now, since the introduction of case-hardened wheels, this objection is entirely removed. Certainly, when the wheels were indented, the increase of friction would almost amount to the difference between the two rails, and this might cause an uncertainty which of the two to be preferred. This having ceased, and the other reasons for preferring the edge-rail still remaining good, together with the saving of weight, by the more proper distribution of the metal to resist the transverse strain of the carriages, renders it no longer a subject of dispute that the edge-rail is decidedly the best.

CHAPTER III.

OF CARRIAGES ADAPTED TO RAIL-ROADS.

It is very obvious that the form of the carriages will depend, in a great measure, upon the nature of the goods to be conveyed in them; many kinds of goods requiring a different sort of carriage. To attempt to give plans of the different forms of carriages to be used upon Rail-ways would be an endless task; I shall, therefore, confine myself principally to the description of the wheels and axles, or other parts, which the nature of the road require should be always of the same form and construction.

The carriages, or, as they were termed, "waggons," used in the first introduction of Rail-ways, were, and still remain, where employed in conveying coals, the frustrum of a pyramid, or in the shape of a hopper; being much broader and longer at the top than at the bottom: the Rail-roads almost universally descending towards the depôt, the fore-wheels were made of greater diameter than the hind-

wheels, according to the angle of the road; the object being to keep the waggon in a horizontal position; the fore end of the waggon, resting on the large wheels, was also made to project considerably further beyond the perpendicular line of the axles of the fore than the hind-wheels, so that the centre of gravity of the load was not midway between the wheels, but much nearer the large wheels than the smaller, and, consquently, laying a greater weight upon them than upon the latter. This form of the waggon has gradually given way to wheels of the same size, and the body of the carriage square, and placed equally upon the two axles, as shown in *Fig.* VII. *Plate* IV.

The wheels were, for a long period, made of wood, composed either of one entire piece, or of two or three pieces fastened together. The mode of making the latter was by joining the pieces together by wooden pins, and securing them by flat slips of iron, in the shape of an S, nailed upon the line of the joining. The periphery of the wheels was hewn into the proper shape, by the workmen, with the axe, with a projection on one side to keep them upon the rail. The axles were made of wrought-iron, and fixed firmly into the centre of the wheels, and, consequently, turned upon

the bearing with the wheels. From the very probable inaccuracy of the workmanship, it is not likely the periphery of the wheels would be perfectly circular, which would cause a sort of jolting or undulatory motion to the load, and thus increase the draught.

To one side, or, in some instances, when steep declivities were to be descended, to both sides of the waggon a brake or lever was attached, which was made to press upon the wheels of the carriage, and regulate the velocity.

a, b, Fig. VII. *Plate* IV. Is the brake or lever, which is called a "convoy;" it is fixed upon the bolt or pin *d*, projecting from the frame of the carriage A B, which serves as a fulcrum; upon the brake at *c c* are attached two pieces of wood, which, when the end *b* of the lever is depressed, acts against the wheels and checks their velocity. At first, these convoys did not extend beyond *d*, acting upon the hind-wheels only as a lever of the second kind; and when very steep declivities are to be passed there were two, one on each side, united together at the end *b* by a bar of wood or iron extending across that end of the waggon, thereby enabling one man to work them both: it was a comparatively modern improvement to extend the lever beyond *d*, and thus embrace both wheels.

The arm or lever of these convoys are either made of wood or of iron; when of wood, pieces of beech, *c c*, called "breasts," are nailed on, which are renewed when worn away: when of iron, they are bolted, as shewn in the drawing, the iron being flattened for that purpose. The end *b* is kept up by a hook, when the convoy is not used, to

prevent the parts *c c* from touching the wheels. In some cases, another lever is used, to give additional power to the man in pressing down the end *b*; this is accomplished by fixing it with a chain upon the frame of the carriage, the chain acting as the fulcrum; another chain, a little from this, reaches to the end *b*, to which it is attached, so that by pressing down the end of the second lever, which is prolonged for some distance behind the end of the waggon, the required purpose is effected.

It seems uncertain at what precise period cast-iron wheels were first introduced. In a dictionary of the arts and sciences, published in 1754, a drawing is given of a cast-iron wheel used upon carriages to convey stones from a quarry near Bath, said to be "a great improvement in some carriages and waggon-ways made use of at the coal-mines near Newcastle;" from whence we may suppose they had not been used there at that period. How long after this they were adopted, I cannot learn; but, in 1765, two wooden and two cast-iron wheels were mostly in use, the wooden ones retained for the application of the brake or convoy.

Great reluctance was shewn, even down to a very recent date, to relinquish the employment of wooden wheels; many objections were urged against the others, their liability to break, to cut the rails, their insufficiency to present an adequate hold to the brake. At first the cast-iron wheels do not appear to have been pro-

perly formed, to avoid the contraction in cooling, and they frequently broke in pieces; increased knowledge of the properties of cast-iron, and of the utility of those kind of wheels, soon produced a general acquiescence in their use.

When cast-iron rails came into use, the wooden wheels could no longer be used, so that the introduction of the former would accelerate the discarding of the latter.

The cast-iron wheels, now formed for the plate-rails, generally of one entire piece, being thicker in the middle to retain the axle, and about two to three inches broad on the rim, and much thinner towards the middle, or nave; many of the carriages, used upon the plate-rails, have wheels loose upon the axles, the latter being either fixed upon the carriage, or running loose upon a bearing or chain. Many different forms of wheels are used, some with spokes, similar to the common cart-wheels, and some solid, with holes cut in them to reduce their weight. The wheels for the edge-rail are almost universally made with six or eight spokes, with a nave about seven inches broad, through which is a square hole to receive the axle, and a rim of about four inches.

Fig. VIII. *Plate* II. will give an idea of their form; *f* is the nave, *a* the rim, with the projecting ledge *b*, called by the waggoners "the crease," to keep the wheel upon the rail.

The rim of the wheel is mostly made a little conical, rather increasing in diameter towards *b*; this is for the purpose of keeping the wheels from rubbing against the sides of the rail with the ledge *b*; the increase in diameter, when the wheel rolls near the inner side of the rim, tends to throw it off towards the other side, and consequently from the side of the rail. It is evident that this ought not to be carried too far, otherwise the motion of the carriage will be very irregular, and the inclined position of the bearing would tend to press the rail outwards, and throw a sort of oblique strain upon it. The height of the ledge is generally about an inch, and practice has shewn this to be sufficient to prevent the carriages from running off the rails.

A very formidable objection to the use of iron wheels was, that the rails, especially when their surfaces were narrow, tended to form or rub an indented groove around each of their rims; which groove, when of moderate depth, not only caused considerable friction, but was liable to break the rails, by a side pressure. The edges also of the top of the cast-iron suffered much by the action of the sides of the groove upon them, and frequently were broken off, on the interior side, for the whole length of the rail. After this, the breadth of the surface of the rails

was increased, which remedied the evil to a certain extent; but the expence of repairs was still considerable.

A complete remedy for this was, however, effected a few years ago, in what is called "case-hardening" the rim of the wheels. This is done by running the metal, which forms the exterior surface of the rim of the wheel, against a cold cylindrical piece of iron; the rapid abstraction of heat by the cold iron produces such a degree of hardness to the metal, that the file has no effect upon it, and this hardness effectually prevents the action of the rail from wearing it into grooves.

Previous to this, the cost of wheels was a very serious charge in the annual repair of the carriages; but the wheels now, when properly case-hardened, work for several years without wearing away. Several, which have been in use for eight years, are still in good order, and, from their appearance, are likely to remain so for a considerable time to come.

The operation of case-hardening was at first attended with great difficulty. The rapidity with which the cold iron caused the rim to cool, prevented the uniform contraction of the metal in all the parts, and made them frequently fly in pieces. The rim being first cooled, did not yield to the contraction of the

spokes in cooling: which, if it did not cause them to separate immediately, left such a tension upon them, that the shocks they received when brought into use soon made them crack, and thus rendered the wheel useless. Many plans were devised to remedy this; in some, the rim was made considerably thicker than the spokes, in the expectation that the latter would cool sooner; in others, the nave was formed in two parts, and afterwards secured with iron hoops.

In Messrs. Losh and Stephenson's patent, to which we have before alluded, there is described a mode of forming the wheels with wrought-iron spokes, in such a way as to yield to the unequal contraction occasioned by the case-hardening of the wheels.

Fig. VIII. *Plate* II. Represents the form of their wheel: *c c c c c c* are the arms, which are of flat malleable iron, dovetailed at the ends. The iron arms being laid in the mould, the cast-iron is run around them, and thus forms one entire wheel. When the arms or spokes are joined to the nave and rim, the dovetailed form, by the contraction in the cooling, causes them to be drawn very firm, and produces a degree of combination which prevents the possibility of their working loose. The spokes were first made straight, as shewn in the drawing, and were six in number, but experience has since shewn that a greater number are preferable; and they are also now made of a serpentine form, like an S, as shewn in the wheels of the convoy carriage, *Plate* V.

This system of case-hardening the rim of the wheels, as before stated, has been found to be of very great utility, reducing the wear and cost to a comparatively trifling amount. The hardness certainly renders them more liable to crack or break by sudden jerks; but this tendency is partly overcome by the rims being made a little thicker now than formerly: the malleable iron spokes also tend, in a certain degree, to obviate this objection.

The axles are universally made of wrought-iron, being square at the ends, to fit the square hole *a*, through the nave of the wheel. Upon the frame of the carriage is fixed a chain, which rests upon the axle, the latter being turned smooth, to reduce the friction as much as possible. Upon the side of this chain a projection is cast, extending beyond the side of the frame of the carriage, which projection, by rubbing against the faced flange, *f*, in the nave of the wheel, prevents the carriage from coming in contact with it; and, being kept well greased or oiled, reduces the friction, when, by one side of the road being lower than the other, the body of the carriage is thrown to one side. These chains have successively been made of wrought-iron, brass, and cast-iron; the latter I consider the most eligible, for reasons which I shall hereafter assign. The size of the

axles will necessarily depend upon the diameter of the wheels, and the weight they have to sustain. Upon the waggons used to carry the coals from the collieries in the neighbourhood of Newcastle, the diameter of the axles are from two inches and a half to two and three-quarters, the weight of the carriage and load amounting to nearly three tons, and the diameter of the wheels about three feet.

CHAPTER IV.

DESCRIPTION OF MOTIVE POWER, AND DISPOSITION OF RAIL-ROADS.

In the early periods of the history of Rail-roads, the disposition of the general line of the road seem to have been an object of little moment. The most of the Rail-roads, descending in the direction the goods were to be conveyed, afforded an easy draught to loaded carriages; and the descent was never so great, but the empty carriages could be easily drawn up the acclivities. In some of the deep ravines, mounds of earth are found thrown up, and in some are sudden and abrupt acclivities partially levelled; but trifling undulations do not

appear to have been noticed. The horses therefore would, along the same line of road, be frequently subjected to very fluctuating degrees of draught. Upon some of the old waggon-ways, the horse is sometimes very heavily strained, and his action is, at other times, not required at all. When the waggon came to some of the descents, it was the custom to unhook him from the fore-part of the waggon, and cause him to follow behind, the waggons running of themselves; the horse thus followed until he arrived at a part of the road where the waggon would no longer run down; he was then again fastened to the waggon, until he arrived at another declivity, when his action was not required; and it was no uncommon thing to find him thus changed several times in the course of his journey.

The only motive power for a long time after the introduction of Rail-ways were horses, and, so long as the wooden rail continued in use, the general load was from two to three tons, including the weight of the carriages. The only guide, in the formation of the road, appears to have been to enable the horse to drag that weight, and the road was sloped accordingly. It is interesting to trace the gradual advancement towards the present state of improvement from the old roads to those successively formed

at the different steps of their progress; and the quantity of goods conveyed, at different periods, exemplify it in a very distinct manner. While the wooden rails without plates continued, the road followed almost always the undulations of the surface, except to avoid steep ascents; and where there was a separate road for the empty carriages, the latter invariably did so; no attempts were made to avail themselves of the action of gravity down the steep declivities; and the most disastrous effects were occasionally produced by the waggons running "a-main," that is, down the steep declivities, a brake, or convoy, only being used, as before stated, to regulate their descent. This brake was pressed by the man with more or less force, according to the declivity of the road, or the velocity with which he wished the waggons to descend. In wet or damp weather, the wheels, by *licking* up the dirt and mud from the rail, became so slippery that the action of the brake was almost destroyed, and the attendant having thus no power over it, it frequently got away, destroyed every thing in its course, killed the horses that were upon the declivity, and finally was dashed to pieces. These accidents were not uncommon, and the destruction caused by them, and the narrow escapes which the men themselves frequently experienced, are

in the recollection of many now living. In wet weather, boys and men were employed strewing ashes upon the rails down the steep declivities, or, as they were termed, "runs," to cause the brake to take effect; and, in some states of the weather, when very steep declivities occurred, the work was obliged to be stopped entirely."*

When the double wood-way came into use, plated with iron, and occasional ascents intervened, more care was taken in forming the road, and a horse was enabled to take a chaldron waggon, containing 53 cwt. of coals, exclusive of the weight of the empty waggon; still, however, the evil occasioned by the waggons "running amain" down the steep declivities, remained."†

* Frequently where very steep descents occurred, for many days the work was laid off on account of the weather; a sudden shower of rain occurring, when any of the waggons were upon the declivity, set the whole away, and men were stationed to draw ropes, as booms across the line of road, to stop their progress. If the ropes could be drawn across before their momentum became very great, the damage was less; but, if they broke the ropes, then the most disastrous effects followed.

† And when the cast-iron wheels were brought into use, the hind-wheels of the waggon were still made of wood, that the brake might be enabled to take a better hold in regu-

The next improvement was, the adoption of iron rails, when the load of the horse was increased to nearly double the quantity heretofore taken upon the wooden rail; which also led to a complete change in the disposition of the road. The brake could no longer afford security to the waggons descending steep hills, and recourse was had to a series of other modes of moving, and of restraining the velocity of the waggon's power, viz. the adoption of what is called, the "self-acting inclined plane." When the gravity of the loaded waggons was employed in dragging the empty ones up the planes, the prevailing means of draught was their horses upon the level and slightly descending or ascending parts of the road, and self-acting planes upon the steep declivities.

Afterwards, when the steam-engine became the most extensive moving power for all other mechanical purposes, its action was employed

---

lating the descent. The brake, for a long time, only acted upon the hind-wheels; and, in that case, I suppose, they found it necessary to retain the wooden wheels, to secure sufficient hold. After it was prolonged beyond the fulcrum, and made to act upon both wheels, the effect being doubled, I presume they found its action upon the cast-iron wheels sufficiently powerful, on such descents as they traversed, to secure the proper hold: the wooden wheels were therefore relinquished.

upon the Rail-road, in dragging the waggons upon the ascents, by means of a rope extending from the engine to the waggons; and, subsequently, the power of locomotion was given to the steam-engine, and it was in that manner applied to drag the waggons along the more level parts of the Rail-road, without the intervention of a rope.

Having thus given an outline of the various species of motive power, successively employed in transporting goods along Rail-roads, I shall now, for the sake of greater perspicuity, treat of them under their separate heads, viz.

1. Horses.
2. Gravity, acting as self-acting planes.
3. Steam-engine, fixed, with ropes.
4. Steam-engine, with locomotion.

I.—HORSES.

Any description of this species of power would be quite superfluous. Of all quadrupeds the horse is the best adapted for use as a moving power, especially in the way that his muscular action can be employed. In dragging carriages upon a Rail-road, we can always adopt the line of draught to the direction of his muscular force, so that the greatest effect is thrown upon the line of traction. When a horse makes an effort to drag a carriage, he bends his body forward, and throws so

much of his weight upon the collar, as is required to overcome the resistance of the carriage. And the muscular force of his legs is employed to keep up this action, and to move his body forward. The effort then resolves itself into two parts—that of the action of the load, and that required to urge his own body forward. No very satisfactory experiments had yet been made to ascertain the precise rates of each, or what proportion the constant exertion which a horse was capable of bestowing upon the load, bore to his own weight.

Dr. Desagulier states the effect at 200lbs., at the rate of two and half miles an hour for eight hours a day; and 200lbs. 20 miles a day. Mr. Smeaton found his performance less. Mr. Watt states it at 150lbs., moving two and half miles an hour. I shall not, at present, enter more fully into this question, other than what is necessary to determine the degree of inclination of road; beyond which it would not, on any account, be prudent, or even practicable, to employ the action of horses.

I shall assume 150lbs. as the amount of a horse's power, at that velocity which should be kept up in conveying goods along a Rail-road. I am aware that occasionally he may be able to exert considerably more power upon the load; but it must be at the expence of time, and

should not, therefore, enter into the calculation. A moderately-sized horse will weigh about 10 cwt. or 1120 lbs. Taking the datum above, we may reckon his muscular exertion divided into eight parts, seven of which are required to urge his own weight forward, and one that of the load. Now, if the acclivity of the road be increased, until the gravity of the horse's own weight amount to that part which he is capable of exerting upon the load, then the muscular exertion will be the same in both cases: he is capable of acting upon the load with a force equal to the seventh part of his own weight; therefore, the angle of inclination will be about 8° 15′, and, upon this acclivity, the exertion required to overcome the gravity of his own weight is equal to the force which he is capable of bestowing upon the load on a level plane.

In laying out a Rail-road, with a view of employing the motive power of horses, all ascents should be carefully avoided; the diminution of his power being so very rapid, that very little effective power will be left for the action upon the load. Even on moderate acclivities, the road should, if the level of the two places will not admit of a moderate inclination, be divided into successive platforms, separated by short ascending planes, upon which some other species of power should be employed.

II.—GRAVITY.

The first introduction of inclined planes, when the gravity of a heavy body downwards was employed to assist or effect the moving of a less heavy body up a plane inclined to the horizon, appears to have been upon canals; when the weight of the loaded boats down were made to draw the empty boats up a sloping plane, from one level to another.

In the year 1788, Mr. Wm. Reynolds completed, at the Kitley Iron-works, an inclined plane, formed of a double iron Rail-road, by which a loaded boat, in passing down a frame constructed for the purpose, drew up some boats which were empty. Since that time many inclined planes have been made on Rail-roads, for the purpose of drawing up the empty carriages by the gravitating power of the loaded carriages down the plane.

On public and other Rail-roads, where the quantity of goods to be conveyed is fluctuating, and is, or is likely to be, the same in both directions, this species of power cannot be resorted to. It is only where a preponderance of goods has to be conveyed in one direction, and where, upon any declivities occurring in the line of road, that preponderance is capable of overcoming the gravity of the returning car-

riages, that the action of gravity can be used to advantage.

It will, therefore, be of importance, in the subject of Rail-road conveyance, to ascertain upon what declivities, with a given preponderating load, this power is available.

The object of all such inclined planes being to convey down a certain quantity of goods in a given time, and to do this with the least expenditure of power; in forming a Rail-road, therefore, with a view of using this species of traction, it is not only necessary that the descent of the plane be such as to give a preponderance to the loaded carriages over those which are empty, but such a preponderance as will cause them to descend and drag up the empty carriages with the requisite velocity. If we give to the plane a greater inclination than requisite, we expose the rope and carriages to an unnecessary strain, and, consequently, to additional wear and cost; and if that inclination be not sufficient, the proper performance will not be accomplished. I shall therefore endeavour to develope the laws which govern bodies descending inclined planes, and afterwards give such practicable illustrations as I trust will render the subject a matter of easy calculation to those interested.

The phenomena of falling bodies is now

well known, as also the laws by which they are governed in falling down inclined planes.

The force with which a body is accelerated down an inclined plane is to the whole gravitating force of the body falling truly, as the height of the plane to its length.

Let H = the height of the plane,
L = its length,
W = the weight of the descending body,

Then the gravitating force of the body down the plane, which may be expressed by G, will be

$$G = \frac{WH}{L} \quad (1)$$

If we make $r = 16\frac{1}{12}$ feet, the space which a body will describe in a second of time, by falling truly, and $x =$ the time in seconds,

Then the space S, which a body will describe upon any inclined plane, in falling t seconds will be

t = time in

$$S = \frac{G \times r t^2}{W} \quad (2)$$

For instance, if the height of the plane be equal to the 36th part of its length, or the descent be one inch in a yard—then, by (th. 1) the force by which the body is urged down the plane will be equal to the 36th part of its weight; and (th. 2) the space which it will describe in the first second of time, will be the 36th part of $16\frac{1}{12}$ feet, or $5\frac{13}{36}$ inches; and, by the laws of falling bodies, the spaces passed over being as the square of the times, the space described, at the end of any other time, will be equal to the square of that time multiplied by $5\frac{13}{36}$ inches.

This will be true when the body descending the plane is without friction; but as no carriage can move without rubbing parts, and, consequently, liable to friction; we must make allowance for this, otherwise the result in practice will not accord with the theorem.

The friction of carriages, moved along Rail-roads, will be afterwards shewn not to differ materially from that of uniform resistance; we may, therefore, express the resistance opposed by friction to the body moving freely down the plane by F, and consider the diminution of the gravitating force of the body, by this cause, equal to the amount of the friction; hence, retaining the former symbols,

$$\text{we have } S = \frac{G-F}{W} + rt^2 \text{ (A)}$$

$$\text{and } F = x - \frac{Ws}{rt^2} \qquad \text{(B)}$$

We can, therefore, determine the friction F of any carriage or waggon by the latter formula, in causing them to descend a certain known declivity; and, ascertaining the space passed over in a given time, the difference between the space actually passed over, and that which the body ought to have described in descending freely, will be the diminution by the effect of friction, and will be a correct estimate of its amount.

Thus, find the gravitating force of the body down the plane, by multiplying the weight of the body by the height of the plane, and dividing the sum by the length; then multiply the weight of the body by the space passed over, and divide this sum by the square of the time in seconds, multiplied by $16\frac{1}{12}$ feet, and subtract this quotient from the gravitating force of the body, and it will give the friction.

This comprehends a body, or system of

bodies, descending an inclined plane, and opposed only by their own friction and inertia; but the principal use in practice is to employ the preponderance of a descending train to drag up the returning empty carriages. The gravitating force has then to be opposed, (in addition to the friction of the descending train,) to the friction or gravity of the ascending train, and also of the rope or chain by which they are drawn up the plane. The gravitating force of the loaded carriages will then be the sole moving power; and the resisting or retarding force composed severally of the gravity of the ascending carriage, and the friction of the whole train.

If we make F' represent the whole retarding force, opposing the motion of the descending train,

and $w =$ the weight of the ascending train of carriages,

Then, as a body requires the same force to propel it upwards, through a given space, which gravity would produce in it by its fall through that space, or the force which a body will acquire by falling through a certain height, will propel it upwards through the same height; consequently, the ascending train of carriages will oppose the motion of the descending train with a force equal to the sum of their friction and gravitating tendency down the plane;

and we have $$S = \frac{G - F'}{W + w} \times rt^2 \quad \text{(C)}$$

and $$F' = G - \frac{(W + w) \times S}{rt^2} \quad \text{(D)}$$

also, - $t = \frac{\sqrt{(W + w. \times S}}{G - F' \times r}$ (E)

This expression of F′ is composed of four distinct parts, viz. the friction of the descending train of carriages; the friction of the ascending train; their gravity; and the friction of the rope.

Make g = the gravitating force of the ascending train $= \frac{w H}{L}$

f = their friction $= g - \frac{w S}{r t^2}$

φ = the friction or resistance of the rope.

Then $F' = F + f \times \varphi + g$.

And having the friction of the carriages and their gravitating force, the friction of the rope will be - $\varphi = F' - (F + f + g)$ (F)

In the application of the inclined plane to practice, it will be requisite, as before stated, that the quantity of work should be done with the least cost; and this will be accomplished when the descent of the plane is such as will perform the work required, without laying unnecessary strain upon the rope employed for the purpose: this can be effected either by employing a commensurate number of carriages upon, or by giving additional elevation to, the plane. Any body, or system of bodies, placed upon a plane inclined to the horizon, will, if the gravitating tendency of the body down the plane exceed its friction, begin to descend, and its motion will be

accelerated according to the laws of falling bodies, and will pass down the plane in a certain time; and this will be the same, whatever be the number of carriages: but, if we employ this system of bodies, or train of carriages, to drag up a certain number of empty carriages by means of a rope, we shall require a certain preponderance of gravitating force to accomplish it in a given time; we can, therefore, either increase the number of carriages until the aggregate sum of their gravitating forces amount to this preponderancy, or we can, by elevating the plane, increase each individual gravitating force until we acquire the same preponderance.

If we are confined to the number of carriages that can be conveyed down at a time, we must then necessarily have recourse to the latter method; but, if no such restriction exist, we can then give to the plane that elevation which will perform the work with the best effect. The proper inclination of planes cannot, however, be found without a perfect knowledge of all the circumstances attending their mode of action: such as the friction, the wear of ropes, &c. I shall, therefore, pass over these considerations at this time, and refer to them again when I shall have detailed the experiments made to ascer-

tain these *facts;* and shall now proceed to describe the mode of action upon the Rail-roads, in the neighbourhood of Newcastle, where their use has been very extensive.

Fig. I. *Plate* III. represents a ground plan of the wheel W W of a self-acting plane, round the rim of which the rope winds, by which the loaded carriages drag the empty ones up the plane. The wheel is generally cast-iron, about six feet diameter, with six spokes, and a grooved rim for the rope to wind upon, the groove being only of sufficient width to hold the rope within it as the wheel moves round; consequently the rope, when in action, only passes round one half of the wheel, from *a* to *b*. At the top of the plane, a square hole is dug, the sides of which are lined with masonry, the top being nearly upon the same level as the Rail-road; the wheel is then placed between two frames of timber, the upper of which, *a b* and *c d*, is shewn in the drawing. They are kept steady by the diagonal braces *e e*. The carriages on which the axle runs, are placed on the front of these frames. The upper one at *g*, and the other immediately below it, on which the ends of the axle that sustains the wheel rests, and on which it is at liberty to run freely round.

At the top of the inclined plane a certain space of ground, for about twenty or thirty yards, (varying according to the number of carriages run down at a time,) is made nearly level, on which the loaded carriages remain until they are to be lowered down, and on which the empty ones stop after their passage up the plane; at the end of this level, or slightly-inclining ground, furthest from the top of the plane the wheel is placed, and small horizontal sheeves, *s s s s s*, are placed in the direction the rope runs, to prevent its being injured by dragging along the ground, and also to diminish its friction. These horizontal sheeves are placed at inter-

vals of every eight or ten yards upon the plane, from one end to the other. The drawing will show the form of their periphery, on which the rope runs, the width being about four inches; their diameter about eleven inches, with a flange on each side to prevent the rope from running off; they are made most frequently to run upon pieces of wood, and sometimes upon cast-iron stands, placed upright upon the middle of the road; the axles are made of wrought-iron, and when they run upon the upright bearings, about three-quarters of an inch diameter. The plane is then made into a proper slope, between the platform or level on which the wheel is placed, and the lower extremity, when a similar flat or piece of level road is made, for the descending train of waggons to land upon. The slope is either uniform, or such as the nature of the ground will permit. Sometimes considerable bends or curves are obliged to be made in the line of the road, but whatever be the form or length of the slope, it must always be terminated at each end by these flat platforms. The narrow parallel lines in the drawing will show the rails as laid down upon the platform; the wheel being placed below the level of the rail: the square hole is covered up, and the rails pass over upon the cover. In the drawing, the rails are broken off at *k k*, the cover being removed to shew the wheel.

The dotted line A A, may be supposed to represent the one end of the platform, and the top of the plane. Three rails r r' r'' are laid from this part nearly half way down the plane, of the requisite width between each rail, for the carriages to run upon, so that both the ascending and descending train pass upon the middle, and upon one of the outer rails: these are continued to where the one train of waggons have to pass the other. The three rails are then made to branch into four, in the same manner as from A A to B B,

for a certain distance, sufficient to allow the carriages to pass each other; these four rails then converge into two or a single line of road, as shewn at *c c*, and are so continued to the bottom of the plane, so that the parallel lines, as shewn in the drawing, will represent a complete passing. The empty, or ascending carriages will be at *c c* when the loaded carriages are at A A, and they will pass each other near D′ E′.

In this form of plane, it will be seen that the loaded carriages pass alternately down the sides D′ D and E′ E. For instance, if they commence their descent at D, one end of the rope being attached to them, and the other end being at E′ E, at the foot of the plane, and fastened to the empty carriages, the loaded carriages will pass down D′ D, and when they arrive at the bottom, the empty ones will arrive at the top, at E. Upon the other side of the plane, the loaded carriages, in the next operation, pass down the side E′ E of the plane, and the empty ones up D′ D.

Upon the canals, and also on several Railroads, a double line of road is laid from top to bottom of the plane, with a double line of rollers or sheeves; but the reader will perceive that, in most cases, the one above described will answer precisely the same purpose. In very short planes, the obliquity of the road, in passing from a double to a single line, will cause a partial retardation to the carriages, and also additional friction to the rope; but upon long planes this is scarcely felt, and the cost of a double road the whole distance would be considerable.

When the slope of the plane is not uniform, descending more rapidly in some parts than in others, or when the descent is so great as to give more than a requisite preponderance to the moving power, a brake is applied to the periphery of the inclined wheel, to equalize or regulate the velocity of the carriages down the plane; and, in many instances, men traverse the plane with each train of waggons, and apply the brake or convoy of the carriages to check their velocity when required. The brake upon the inclined wheel will be perceived to have no power in checking the velocity of the carriages more than what is equal to the hold the rope takes upon the wheel in passing round its semi-periphery, for if the excess of gravity of the loaded carriages, above what is required to overcome the whole retarding forces, be greater than the hold of the rope, the wheel may be completely stopped, and the rope slide round the wheel, which, in some instances, might be attended with danger. The declivity of the plane should never be so great as to cause such an excess or preponderance of gravity, when such a wheel as this is used.

Many other plans of employing gravity as a moving power, have been resorted to by different persons. In very steep planes, horizontal

rollers, similar to A. B. *Fig*. II. *Plate*. III have been used; when the descending train unwound the rope from its barrel, and wound the rope upon the barrel of the returning carriage, which was again in its turn unwound by the descending train; in such a combination, the brake could be employed with any degree of force thought proper, as the rope and barrel were one machine, and the rope could not move round without moving the barrel also.*

Skeleton waggons, loaded with metal, are sometimes made use of to overhaul the rope by which the empty waggons were drawn up the plane, and to drag it down the plane again; and also, at the same time, to drag the rope up by which the descending train was lowered, for the purpose of allowing the descending train always to pass down the same line of road, and the ascending train to travel up a different road, each having a separate rope. I do not see, however, that this mode can be of advantage, except under very peculiar circumstances, for the moving power

---

* The first self-acting inclined plane, erected near Newcastle-upon-Tyne, was by the late ingenious Mr. Barnes, on which the descending train of waggons drew up, out of a pit or well sunk at the summit, a plummet of considerable weight; which plummet, in its descent, drew the empty carriages up the plane.

is surely subjected to a resistance equal to double the amount of the friction of the rope; and the rope is also subjected to a similar excess of strain, above what arises on the common form of plane, when the loaded carriages always pass down the road, and the empty ones traverse upwards, and vice-versa.

The mode by which the carriages are made to pass, from one kind of road to another, upon the plane described in *Plate* III. *Fig*. I., is at once simple and effective, and is done without the aid of manual labour.

The ledge, or projecting flange, which directs the wheels of the carriages upon the rails, is upon the inner side of the rim of both the wheels, and, consequently, travels on the inner side of the Rail-road. When the rails diverge into four, and thus form two separate roads, as from A A to B B, two rails are made to join into one, as shewn in the figure; and the carriages, in the different tracks, pass into the double road without the least obstruction, as will readily be seen on inspecting the drawing, keeping it always in mind, that the projection, which guides the wheels, traverses against the inside of the rail. Again, in passing from a double line into the single one, viz. along the road E E′, towards C C, it will be perceived that the carriages will be inclined to traverse that track only; but, in passing from a single line into a double one, as from C C′ to B B and B′ B′, some contrivance is necessary to direct the carriages into the proper track; for this purpose rails, moveable on a centre, as *f f′*, *Plate* III., or shewn on a larger scale at *f*, *Fig*. X. *Plate* II., are used, which, being made to block up, as it were, the opening into the wrong road, and, at the same

time, act as a check to direct the wheels into the proper one, performs the desired effect. Thus, suppose a train of waggons to have passed down D D′, then the moveable rail "switch," or "pointer," *f*, will be thrown out from the rail *c*, into the position shewn in the drawing, and the opposite one *f*′, will be pushed close against the inner side of the opposite rail, as shewn in the drawing. Then, on the return of the next train of carriages, which will be the ascending ones, they will pass up the same side, D′ D, for the rail *f*′ will prevent them from passing up the other; and this, the reader will perceive, is the track they ought to pass up, being that which the loaded carriages descended. The ascending train passing up D′ D, the descending train will, of course, pass down E E′; when it arrives at the moveable rails, or switches, it will put them into the reverse position, *f* will be pressed against the inner side of the rail *c*, and *f*′ will be thrown out by the flange of the wheel into the position shewn by *f*′. The dotted lines will represent the position of these rails, after the descending train has passed, which will be perceived is that which is required to direct the returning carriages into the road E′ E, up which they are to pass.

Gravity being a moving power so very economical, it is of the utmost importance that its aid be extended to every situation, and in every case where its application is available. Friction being the great obstacle, in the extension of its application, it is desirable that every means be tried to exterminate it as much as possible. The plan drawn in *Fig.* I. *Plate* III. will, I am inclined to imagine, be found to be a mode of application, when the annihilation of friction has been effected to as great an

extent as any plan yet devised; it has this to recommend it, that it has been very extensively used in a district where almost every means had been resorted to in the economy of conveying goods, and every other plan has yielded to its adoption, when the diminution of friction became an object.

The simplicity of the construction of this kind of wheel, and the manner of placing it, concealed from the view and sheltered from the weather, are also objects which recommend it. In addition to these, on the score of diminishing the friction, barrel-rolls, when the rope winds upon itself, have been used, as before stated, when the excess of preponderance rendered it necessary; but these requiring double ropes, the other plan is, on that account, superior.

The amount of friction being always proportionate to the extent of rubbing surface, by placing the rope upon sheeves, and causing it to pass down the plane, along their peripheries, we diminish it in the ratio of the diameter of the sheeves to the diameter of the axle; hence the larger the diameter of the sheeves the better, provided the weight of the sheeves is not thereby increased. It is also necessary that the surface of the sheeves, whereon the rope traverses, when running, be always of the same radius; for, if the rope runs upon a sur-

face not every where the same distance from the centre of motion, it must experience a rubbing from the different velocities of the surface of the sheeves at the different radii, the velocity of the rope, in every part, being the same, similar to a flat surface rolling along the periphery of a conical sheeve. The sheeves, shewn in the drawing, are made quite flat, with side flanches, to keep the rope on; but their width will appear greater than requisite, being on an enlarged scale; the general width is from three to four inches, and from eleven to twelve inches diameter, where rope runs, and weighing about 21 to 25 lbs.

The limit in the application of self-acting planes will be, when the preponderance of the gravitating force of the descending train of carriages are sufficient to drag the ascending carriages up the plane with the requisite velocity, and always upon descending lines of road.

III.—STEAM-ENGINE,

FIXED UPON ASCENDING PLANES.

The preceding planes, as before stated, are necessarily descending planes, down which the goods are supposed to be conveyed, and up which only the empty carriages, or a very

small portion of returning carriages of goods are supposed to ascend. In the prosecution of general lines of road, extending from place to place, distant from each other, and between which the face of the country is perhaps uneven, undulating, and hilly, we cannot always divide the line into platforms, or stages, with little inclination: and when we descend planes, we frequently meet with acclivities which cannot possibly be avoided, up which the loaded carriages must be conveyed: also, in public lines of road, when the carriage is, perhaps, the same in both directions, or even though the preponderance may be in one direction, when loaded carriages occasionally have to pass and repass, it is necessary that a passage should be afforded to the transit of goods. I shall, therefore, now describe the means which have been practised to surmount such ascents with the loaded carriages.

I have previously described the action of two kinds of motive power, viz. HORSES and GRAVITY. —The former has been explained to be limited in action to very inconsiderable acclivities; the latter to declivities solely. Hence the kind of power which is the subject of this chapter will comprehend all other inclinations of road; whether they be level, ascending, descending,

or undulating. It will not here be attempted to point out the particular degree of inclination or elevation which should be observed in surmounting the summit of a hill, nor how far it may be adviseable to divert the line to obtain a certain inclination of plane, or to avoid such a rising ground.

I shall first of all describe the different methods of surmounting those ascents, which occur in some of the principal Rail-roads that have come under my observations; and, afterwards, compare the effect on different planes with each other, by which we may be able to deduce some practical data for the guidance of engineers in laying out the most advantageous line, or the most beneficial inclination of planes across the country through which a Rail-road is to be carried.

The dragging of boats upon canals, from one level to another, to save lockage-water, by means of sloping planes, has been long in use; but the introduction of steam-engines to drag carriages up ascending planes upon Rail-roads, is comparatively recent. Mr. S. Cooke, in 1808, erected an engine upon Birthy-fell, in the county of Durham, to draw the loaded carriages of the Inpeth colliery across the Durham and Newcastle turnpike-road, up a

steep ascent; and since that time they have been much used upon the Rail-roads in the neighbourhood of Newcastle.

The following are the different kinds of planes with which I am acquainted, and the manner of surmounting them:—

1. Plane, or inclination, when the gravity of the carriages which have to pass downward *is sufficient* to drag the rope after them, by which rope the returning trains are drawn up by a steam-engine. This may be divided into single or double lines of road; if single, one train of carriages only are in action at a time, and one rope only is used, the descending train drawing the rope out upon the plane to which the ascending carriages are attached, and thus drawn up.

2. If double, then there is a double line of road, or one similar to a self-acting plane; the descending train of carriages passing down one side, and the ascending train are drawn up at the same time. In this case, if there be any excess or preponderance of gravity in the loaded carriages, above that which is required to drag the rope down the plane, this preponderance comes in aid of, and assists, the engine in dragging the returning carriages up the plane.

3. When the carriages are to be conveyed

up a plane, the acclivity of which is *not sufficient* to enable the returning or descending carriages to drag the rope after them.

In the double line, No. 2, a sheeve has been placed at the bottom of the plane, round which a rope is passed, attached at one end to the ascending carriages, and at the other to the descending carriages; the engine, in drawing up the loaded carriages, by means of the rope attached to them, winding round the sheeve at the bottom of the plane, drags the empty carriages down the plane at the same time.

4. When the whole line consists of a series of such planes, or is undulating, other engines are placed in extension of the plane above alluded to, with sheeves at the end of the planes, to drag out the ropes when the declivity of the plane is not sufficient; thus forming a succession of planes with endless ropes or chains.

5. When a hill is to be passed on one side, and on the other side carriages traversing in the same direction, are to descend, an engine is placed upon the summit of the hill. In some cases, this engine, with a single rope, draws up the carriages, and then lets down the same carriages on the opposite side. When the road is double, similar to No. 2, sheeves are placed at the

bottom of the two planes, and the engine thus draws the carriages, in both directions, upon the two planes at the same time.

6. By forming the whole line into a succession of engine-planes, or stages, of suitable distances apart. At each end of these stages a stationary engine is erected, to draw the carriages from the last stage, or engine, towards itself. This operation is performed by means of ropes, which are, in the first place, taken from the several engines to the engines immediately preceding them, by means of horses; but when the work has commenced, and the carriages have begun to travel backwards and forwards upon the line of Rail-road, the respective ropes are carried from one engine to another, by being hooked at the end of the advancing and returning carriages.

Those engines act not only upon the intermediate stages, but, also, in a similar manner, upon the stages beyond them, in conjunction with other engines placed at the extremity of the stages. These latter engines again, with others beyond them, and so on throughout the whole length of the line; thus forming a series of engines, from one end of the line to the other, acting in the manner thus described, and reciprocating with each other. This mode has been made the

subject of a patent by Mr. B. THOMPSON, of Ayton Cottage.

By these modes, any ascents or undulations may be passed, which occur in the line of road to be traversed. Where the line is laid out into successive platforms or level stages, and short ascending and descending planes, any of the modes, No. 1, 2, 3, and 5 may be used, as the nature of the plane may be; and, when the whole line is divided into engine-planes, either the mode No. 4 or No. 6; the one with a double rope, when the carriages on each plane are passing and repassing at the same time; and the other with single ropes, when the carriages alternately pass and repass, may be used.

I shall now attempt, with the aid of the drawing, *Fig.* II. *Plate* III., to describe more particularly the mode of action of the different planes above enumerated; but, first of all, I must premise that steam is the motive power employed, though it is not absolutely necessary that it should be so. Water, animal, or even manual labour might, and may, in particular cases, perhaps, be employed with advantage on a small scale, when the ascents are trifling, and the transit of goods comparatively small; but, as my object is to illustrate the different modes upon extensive lines, where traffic is considerable, and celerity the great desi-

deratum, I shall suppose that the motive power is either steam or water. The reader will find a very able account of different methods of overcoming short ascents, by means of animal power, as described by Mr. Scott, in the Transactions of the Highland Society, vol. IV.; as also other matter on Rail-roads worthy of perusal.

It will not be necessary to give a drawing of either a steam-engine or a water-wheel, whichever be made the source of motive power, as these are now so well understood, and their mode of action described in so many publications, that the reader will here feel no loss in the want of them. I shall, therefore, suppose that

a b, *Fig.* II. *Plate* III. represent the shaft communicating the action of the moving power to the machinery, which may be the shaft of a steam-engine, or a water-wheel, as the case may be. If the former, *a c* will shew the crank and *d e* the fly-wheel; *f* is a cog-wheel fixed upon this axle, and giving motion to the rope-rollers A B, by means of the cog-wheels *g h*. These rollers are alternately thrown out of geer, or disengaged from the action of the cog-wheels, by any of the common methods of disengaging machinery. In this drawing the axles of the rollers are turned round, so that when the axles are fixed, the rollers are at liberty to move freely round; levers are fixed upon a detached part of the building, moveable upon a fulcrum at *i i*, one end of which can be moved at pleasure. The other end passes within, but does not touch, (when the machinery is in action) the two parallel flanches fixed upon the side of the roller, but which, when moved backwards and forwards in the line of the axle, throws the projections of the clutches *k k* either within

or clear of each other; and, consequently, either engages or disengages them from the action of the moving power. Similar clutches are placed upon the other end of the roller in the interior, to equalise the twist upon the axle, but which are not shewn in the drawing; the whole is placed upon the bearings *l l*, &c. resting on a frame of wood upon the wall of the building, and elevated sufficiently high that the carriages can move along the Rail-road immediately underneath without touching, and is covered over to preserve the whole from the action of the weather.

In the mode No. 1, when the transit is not greater than requires one single road, and the ascent is for the purpose of conveying the carriages from a lower to a higher level, a single roller, A, only is requisite, with a single rope *r r*, reaching from one end of the plane to the other, and passing over sheeves, similar to S. When the carriages are drawn up the single road, (represented by the narrow parallel lines to F F,) the road then branches into separate roads, as shewn by *c c*, *Fig.* I. and the carriages are conveyed from thence by other means. The reason why the road branches from one single line into two is, to enable the carriages, traversing different ways, to pass each other. When the carriages are drawn up the ascent into the road allotted to them, the descending carriages are then put in motion, and the roller A being thrown out of geer, as shewn in the drawing, their gravity causes them to run down the plane, and drag the rope after them, which is again ready for drawing the ascending carriages up the plane, when the roller A is thrown into geer, and is again ready to drag the carriages up the plane.

No. 2.—When the transit of goods is such that a single road is not adequate, then the means come under the head No. 2. When the carriages are drawn up and pass down the plane at the same time, these rails are laid down, as shewn at *Fig.* I. and the plan in many respects is similar to this. Two rope-rollers are then used, as A, B, when in action, but they

are continually in geer, or attached to the shaft *a b*, and are placed in the line of their respective roads, so that the ropes passing upon the centre of the road D D′, *Fig.* I. would correspond with the middle of the roller A, and the rope of the road E E′ be in a line with the roller B. Sometimes the construction is precisely the same as shewn in *Fig.* I. when the descent of the plane is such as to afford an excess of preponderance in the gravity of the loaded carriages, nearly adequate to drag the empty carriages up the plane. Either a horizontal sheeve, similar to *Fig.* I. or a like sheeve placed perpendicular upon the axis of the engine, is made to revolve, and thus to drag the carriages up the plane. This, of course, cannot be done where the resistance of the carriages is greater than the friction, or hold of the rope upon the groove of the sheeves, for in that case the wheel would be turned round without effecting the ascent of the load. Sometimes the friction of the rope upon the sheeve is increased by the addition of small sheeves crossing the ropes obliquely to the line of the plane. When the latter sheeve can be applied it is of advantage, as it precludes the necessity of having two ropes, which, when in the rollers, where the rope winds upon itself, as in *Fig*. II. is indispensible. In both these cases, whether the rolls A B, *Fig*. II. or the single sheeve, *Fig.* I. be employed, the formation of the road, and the manner of placing the rails to enable the carriages to pass each other, are precisely the same as previously described for the self-acting plane; and may be either double the whole length, or with three rails above the passing on the middle of the plane, and two rails below.

No. 3.—On the description of planes, No. 3, the action does not materially differ from that last described, only the ropes must be double, and must necessarily wind upon barrel-rollers, as A B, *Fig*. II. The sheeves, at the bottom of the plane, may be the same as *Fig*. I. round which the rope that draws the descending carriage down winds. In this

there must be three ropes, each the whole length of the plane, one for each roller, and one stretched along the line of the plane, to draw the descending carriages down, called the "tail rope." The road will consist of three rails, (as at A A) the whole distance, except where it branches into two separate roads, (as at B B) in the middle of the plane, for the carriages to pass each other. The action of this plane will be readily understood. Thus, suppose the sheeves W W, *Fig.* I. to represent the sheeve at the bottom of the plane, and the train of carriages fastened to the rope D D′, at the bottom of the plane, as at D, ready to be drawn up by the engine; the rope which winds round the sheeve will be in the position shewn in the drawing, and will be stretched the whole length of the plane, and reach to the summit, where it is attached to the team of descending carriages. The action of the engine is then employed to drag the ascending carriages, D, up the plane in the direction D′D, which will, also, pull the rope E′ E round the sheeve, and with it the descending train of carriages down the plane; and when the ascending carriages arrive at the top of the plane, the descending train will have arrived at the bottom, at E. When the ropes are disengaged from the carriages, and fastened to those which have to traverse the opposite direction, the rope E′ E is drawn, in its turn, up the plane, with the ascending carriages, by the engine, and the rope D′ D thus drawn down with the descending carriages.

No. 4.—No. 4 is only an extension of this when the sheeve would be placed nearer each other, and the engines at the extremity of the respective planes. In traversing a country by means of a series of these double planes, the ropes employed will necessarily be three times the length of the line of road, though more than what is equal to twice the length is never in action at one time. If a descent occur in the line when the gravity of the carriages are capable of dragging the rope after them, then the tail-rope and sheeve may be dispensed

with; but when such is not the case, then the whole length must be furnished with such ropes and sheeves.

No. 5.—When an isolated hill is to be ascended, and immediately after it a descending plane occurs, and it is not practicable to cut or drive a tunnel through it, an engine is placed upon the summit which drags the carriages upon both planes. If the traffic requires only a single road, then one roller, such as either A or B, *Fig.* II. is all that is required upon the engine axle. Thus, suppose the train of carriages attached to the rope *z z*, the roller B being in geer, the engine then drags them up the plane to G G, from whence the road is made to descend gradually to F F, so that the carriages will run by themselves, the rope continuing attached to them: After they arrive at F F, the roller is thrown out of geer, as shewn at A, and they run down the plane, dragging the rope after them. To this rope the carriages which are to be drawn up this plane are attached, and the roller being thrown into geer, or connected with the action of the engine, the carriages are drawn up the plane, until they arrive at R R, when the road again gradually descends to T T, to cause the carriages to run without assistance, when they thus arrive at the top of the opposite plane, down which they run and drag the rope after them, ready to be used to bring another train up the plane. This mode of traversing ascents is supposed to be used when the gravity of the carriage down each plane is sufficient to drag the rope after it. When the descent is not rapid enough, double or endless ropes have been used with a sheeve at the bottom of each plane, as previously described.

No. 6.—When the whole distance to be traversed is divided into successive stages, with fixed engines alternating with each other by means of ropes, throughout the whole line. In this mode each engine is furnished with two rope rollers, say A and B, *Fig.* II. While the roller B is employed in drawing the train of carriages, by means of the rope *z z*, up

the plane, the carriages are drawn down, in the other direction, by the engine at the further end of the opposite plane; and, also, the rope *r r* attached to them; which, when it arrives at the end of the plane, and the returning carriages are attached to it, the roller A is made to drag the carriages towards this engine, and with them the rope from the other engine; in like manner, while the roller B is dragging the carriages towards itself, it also drags with it a rope from an engine at the other end of the plane, and with it a rope, which is used to drag the carriages and the rope *z z* from the roller B. Each engine in the train therefore has two rollers, one for the purpose of reciprocating with a rope from the engine at the extremity of the plane, on the side next which it is placed; as, for instance, the roll B with an engine at the end of *z z*; and the other for reciprocating with the rope-roller of the engine at the extremity of the plane, in the opposite direction, as A with the plane *r r.* : at the one end of the train of carriages, therefore, the end of the rope from one engine is affixed, and at the other end of the same train of carriages the end of the rope, from the other engine, is fastened. When, therefore, the roller B, for instance, is made to wind the rope upon itself, it drags the carriages forward towards its engine; and the rope from the other engine being attached to the carriages, it is also drawn out from its roller; and when the carriages arrive at T T, the whole of the rope *z z* will be wound upon the barrel B, and the end of the rope of the other engine, at the end of the stage, will be at T T. The returning carriage is then made fast to this last-mentioned rope, and they are drawn along the stage by the engine at the extremity; and the end of the rope *z z* being attached to them, it is also unwound from the roller B, ready to draw the carriages towards it, when necessary. In the same way the roller A is made to reciprocate with the engine, at the extremity of the stages, in the opposite direction; the train of carriages upon the planes, on each side of the en-

gine, always travelling in the same direction, with respect to the line of the road, or in opposite directions, with respect to the engine; the one train moving from the engine, and the other towards it; and this takes place with all the engines upon the line. In this plan of action, the excess of the gravitating force of the carriages passing from the engine, above what is required to overcome their own friction and the resistance of the rope, is made to aid or assist their engine, in dragging the carriages towards itself upon the other plane. Thus, if the rollers A B be both in geer, and the carriages descending the plane F F, and dragging the rope after them; if their gravity exceed their own friction, and that of the rope, the excess will assist the engine in dragging the carriages up the plane T T; and the same will happen upon the other plane, and also on any other throughout the line. Thus no power is uselessly expended.

To accomplish this mode of action, ropes twice the length of the plane will be required, though only a quantity of rope equal to the single length of the plane, or the distance to be traversed, is in action at once: and the carriages have to move with a velocity equal to twice the effective speed; thus, to secure a passage or trip at the rate of four miles an hour, the carriages have to move at a velocity of eight miles an hour; or, to travel forty-eight miles in twelve hours, the carriages must be moved at the rate of eight miles an hour, exclusive of delays in changing, as the carriages travelling in any direction have always to remain at the engine-house, where they are drawn up to the end of the stage, until the

carriages, passing in the opposite direction, arrive at the same place from the other end of the plane.

The difference between the double plane, No. 4, with an endless or double rope, and the single, or reciprocating one, is, that in the former the carriages are continually moved or moving along without interruption, at the end of the stages, except the delay in changing, and will thus, in travelling at the rate of four miles an hour, traverse a distance of forty-eight miles in twelve hours, with the action of three ropes, acting as a double one the whole distance; and, in the latter, the velocity must be doubled, to effect the same distance in the same time; or, to traverse forty-eight miles in twelve hours, must go at the rate of eight miles an hour, with the alternate action of two ropes forming one continually active rope the whole distance: there will, however, be a difference in their effect, above what arises from the relative friction of the ropes upon the plane, by the application of the sheeve, the action of which is rather different from that of a rope-roller, and which will be considered after the friction of the rope has been ascertained.

These different modes will then effect the conveyance of goods over any kind of country, whether flat, hilly, or undulating; and whe-

ther the line be divided into successive platforms or levels, and ascending or descending planes; or be stretched at once across the country without regard to any particular inclination: either one or other of these modes, as the case may be, will comprehend means for securing the regular and constant transit.

IV.—STEAM-ENGINES

BY LOCO-MOTION.

The steam-engine, for many years subsequent to its discovery, was solely employed in lifting or raising water by means of pumps. Savary, Newcomen, Beighton, Desagulier, and other eminent men, successively contributed their aid to its improvement and its advancement in utility; still it was cumbrous, heavy, unwieldy, and complicated, and its use confined within narrow limits. It was in this state that Mr. Watt found it, and to his enterprising genius the world is indebted for one of the most useful machines ever given to commerce and the arts. Its action was no longer confined to a rectilinear motion, or that of pumping water; but, through his assiduous exertions, converted into a rotatory motion, and applied to almost every manufactory.

So early as the year 1759, steam appears to have been thought of as a motive power to wheel-carriages. In a note to the last edition

of Robison's 'Mechanical Philosophy,' Mr. Watt states—"My attention was first directed, in the year 1759, to the subject of steam-engines, by the late Dr. Robison, then a student in the university of Glasgow, and nearly of my own age. He, at that time, threw out an idea of applying the power of the steam-engine to the moving of wheel-carriages, and to other purposes; but the scheme was soon abandoned, on his going abroad." Mr. Watt, it appears, soon after made an experiment with steam acting by its expansive force, but relinquished the idea of constructing an engine upon this principle: "I, however," says he, "described this engine, in the fourth article of my patent, in 1769; and, again, in the specification of another patent, in the year 1784, together with a mode of applying it to the moving of wheel-carriages."

For many years subsequent to this, the improvement of the steam-engine, acting by condensation, seems to have wholly occupied the scientific world; and the use of steam, acting by its elastic force, entirely abandoned or neglected. Mr. Hornblower had a patent, for the application of steam, acting both by its expansive force, and by condensation; but it is to Messrs. Trevithick and Vivian that we owe the introduction of the steam-engine, acting solely by the expansive force of the steam. In

March, 1802, they obtained a patent for the application of that species of power to propel carriages upon Rail-roads.

Mr. WOOLF, a short time after, made a series of experiments, to develope the law of action of steam, at different degrees of elasticity, which he explained, in his patent of June 7, 1804, and, since that time, high-pressure steam-engines have been much used, in many parts, to economise the fuel.

Messrs. TREVITHICK and VIVIAN, in the specification of their patent, give a drawing of their engine, applied to move a carriage upon the common roads, which may be seen in the *4th vol. Rep. Arts, 2d Series, p.* 241. The carriage there delineated resembles in form the common stage-coaches, used for the conveyance of passengers; a square iron case, containing the boiler and cylinder, is placed behind the large, or hinder, wheels of the carriage, and is attached to a frame, supported from the axles of those wheels. The cylinder was in a horizontal position; and the piston-rod was projected backwards and forwards, in the line of the road towards the front of the carriage. Across the square frame, supported by the wheel of the carriage, an axle was extended, reaching a little beyond the frame on each side: this axle was cranked in the middle, in a line with the centre of the

cylinder, and a connecting rod, passing from the end of the piston, turned this axle round, and produced a continued rotatory motion of it when the piston was moved backwards and forwards in the cylinder. Upon both ends of this axle cog-wheels were fixed, which worked into similar cog-wheels upon the axle of the wheels of the carriages, so that, when a rotary motion was produced in the cranked axle by the piston-rod, the rotatory motion was communicated to the axle of the larger or hinder wheels of the carriage; and these wheels being fixed upon, and turning round with the axle, gave a progressive motion to the carriage. Upon one end of this axle was fixed a fly-wheel, to secure a rotatory motion in the axle at the termination of each stroke.

The four wheels of the carriage were of the usual form, which, turning to different angles with the body of the carriage, directed its motion upon the road; and, in cases where abrupt turns of the road required sudden changes in the direction of the carriage, the toothed or cog-wheels, on either side, could be thrown out of geer, and the opposite wheel made to drive the carriage into the proper obliquity of the road.

Upon the periphery of the fly-wheel, a brake was attached, to regulate the descent of the

carriage down steep hills. The contrivances, to effect the requisite motions of the various parts of this machine, are extremely ingenious; and, considering it as the first which directed public attention to the subject, is entitled to great commendation.

The many objections to its application, upon public turnpike-roads, may, I presume, have operated in preventing the patentees from carrying it into practice in the manner described in their specification; they, therefore, very properly, directed their attention to its use upon Rail-roads.

Two years after the date of this patent, we find that Mr. TREVITHICK made an engine in South Wales, which was tried upon the Merthyn Tydvil Rail-road. The engine is stated to have had an eight-inch cylinder, with a four-feet six-inches stroke, and "drew after it upon the Rail-road as many carriages as carried ten tons of bar-iron, from a distance of nine miles, which it performed without any supply of water to that contained in the boiler at the time of setting out; travelling at the rate of five miles an hour."

As there is no account given of the inclination of the road, we cannot judge of the real performance of the engine. It had, it appears,

only one cylinder, and, from what I can learn, did not materially differ, in construction, from that previously described, except in the form of the carriage.

The great obstacle to their introduction at that time, was the supposed want of hold or adhesion of the wheels upon the rails to effect the loco-motion of the engine. Messrs. TREVITHICK and VIVIAN, in their patent, recommended making the external periphery of the wheels rough or uneven, by using projecting heads of nails, bolts, or cross-grooves; or, in case of a hard pull, to cause a lever, bolt, or claw to project through the rim of one or both of the said wheels, to take hold of the ground. But it will appear obvious to any one, that this mode of remedying one defect would be the means of producing another; for any projections would not only cause considerable resistance to the progressive motion of the engine, but would also tend to injure the rails of the road.

To obviate these defects, Mr. BLENKINSOP, of Middleton colliery, near Leeds, in 1811, obtained a patent for the application of a rack, or toothed rail, stretched along the whole distance to be travelled, into which wheels, turned by the engine, worked, and thus produced a progressive motion in the carriage.

Fig. I. *Plate* IV. will convey a pretty correct idea of the mode of action of this kind of engine. R R is a piece of iron of the rails constituting the Rail-road, on the side of which are cast the semicircular protuberances or projections 1. 11. &c. these semicircular teeth project from the side of the rail two or three inches, thus forming a longitudinal toothed rack, which is extended the whole length of the road. *a a* are the cylinders, placed within the boiler. The action is communicated by the pistons to the connecting rods *b b*, which transfer the motion to the cranks *c c*, turning upon axles attached to the frame of the carriage. Upon the axles on which these cranks are fixed, are also fixed the pinion-wheels *d d*, which are turned round by the cranks; these two pinion-wheels communicate with a larger cog-wheel, *e*, in such a manner that both contribute in producing a rotatory motion in it. The axle of this cog-wheel, *e*, extends to the outside of the frame of the engine, and upon the end of it is affixed the larger toothed wheel *f*, which is thus turned round by the large cog-wheel, and consequently by the action of the engine; and the teeth of this cog-wheel being made to correspond, will lay hold of the toothed projections on the side of the rail, a progressive motion of the carriage is thereby effected. The steam, after performing its office in the cylinder, is allowed to escape into the atmosphere, through the pipe *e*. The boiler is cylindrical, and is heated by a circular tube passing through it, terminated at one end by the chimney. The toothed or rack-rail is only laid on one side of the road, the other being common rails. The cog-wheels can be varied in size according to the different velocity with which it is required to travel.

By the use of this rack-rail the engine is enabled to ascend acclivities which Mr. Trevithick's engine, from the want of adhesion,

could not surmount; accordingly its use is extended.

Mr. Blenkinsop, soon after the date of his patent, erected some of his engines, and employed them upon the Middleton colliery Rail-road, in sending coals to Leeds, where they have ever since been used.

The engine erected by Mr. Trevithick had one cylinder only, and a fly-wheel, to secure a rotatory motion in the crank at the end of each stroke. An engine of this kind was sent to the North, for Mr. Blackett, of Wylam, but was, for some cause or other, never used upon his Rail-road, but applied to blow a cupola at an iron-foundry in Newcastle. Mr. Blackett however had, in 1813, an engine of this kind made, and set upon his Rail-road, which worked by the adhesion of its wheels upon the rails. Still the supposed want of adhesion formed the great obstacle to their introduction, and the attention of engineers was directed to obtain a substitute for this supposed defect.

In December, 1812, Messrs. William and Edward Chapman obtained a patent for a mode of effecting the loco-motion of the engine, by means of a chain stretched along the middle of the Rail-road, the whole length, properly secured at each end, and at proper intervals. This chain was made to wind partly

round, or to pass over a grooved wheel, turned by the engine, of such a form that the wheel could not turn round without causing the chain to pass along with it. When this wheel was turned round by the engine, as the chain was fastened firmly at the end, it could not be drawn forwards by the wheel, the carriage was therefore moved forward in the line of the chain.

The carriages containing the goods were attached to the engine-carriage, and thus conveyed along the Rail-road.

At intervals of every eight or ten yards, the chain was secured by means of upright forks, into which it fell when left at liberty; this was for the purpose of taking off the strain from part of the chain, when more than one engine was travelling by it.

The chain was prevented slipping, when the grooved wheel was turned round, by friction-rollers pressing it into the groove.

Mr. Chapman had one of his engines tried upon the Hetton Rail-road, near Newcastle, but it was soon abandoned; the great friction, by the use of the chain, would operate considerably against it, and also its liability to get out of order.

In 1813, Mr. Brunton, of Butterley iron-works, also obtained a patent for a mode of accomplishing the loco-motion of the engine

without the aid of the adhesion of the wheels upon the rail, and of which, as it displays great ingenuity, I have given a drawing.

Fig. II. *Plate* IV. is a side-view of the engine. The boiler was nearly similar to that of Mr. BLENKINSOP, semicircular; there was a tube passing through it, to contain the fuel. The cylinder A was placed on one side of the boiler; the piston-rod is projected out behind horizontally, and is attached to the leg *a b* at *a*, and to the reciprocating lever *a c*, which is fixed at *c*; at the lower extremity of the leg *a b*, feet are attached, by a joint at *b*; these feet lay a firmer hold upon the ground, being furnished with short prongs, which prevent them from slipping, and are sufficiently broad to prevent their injuring the road.

On inspecting the drawing, it will be seen that when the piston-rod is projected out from the cylinder, it will tend to push the end of the lever, or leg *a*, from it, in a direction parallel to the line of the cylinder; but as the leg *a b* is prevented from moving backwards, by the end *b* being firmly fixed upon the ground, the reaction is thrown upon the carriage, and a progressive motion given to it, and this will be continued to the end of the stroke. Upon the reciprocating line *a c* is fixed at 1. a rod, 1. 2. 3., sliding horizontally backwards and forwards upon the top of the boiler; from 2 to 3 it is furnished with teeth, which work into a cog-wheel, lying horizontally: on the opposite side of this cog-wheel a sliding-rack is fixed, similar to 1. 2. 3. which, as the cog-wheel is turned round by the sliding rack 2. 3. is also moved backwards and forwards. The end of this sliding rod is fixed upon the reciprocating lever *d c* of the leg *d e*, at 4. When, therefore, the sliding rack is moved forwards in the direction 3. 2. 1. by the progressive motion of the engine, the opposite rod, 4, is

moved in the contrary direction, and the leg $d\,e$ is thereby drawn towards the engine; and, when the piston-rod is at the farthest extremity of the stroke, the leg $d\,e$ will be brought close to the engine: the piston is then made to return in the opposite direction, moving with it the leg $a\,b$, and also the sliding rack 1. 2. 3.; the sliding rack acting on the toothed wheel, causes the other sliding rod to move in the contrary direction, and with it the leg $d\,e$. Whenever, therefore, the piston is at the extremity of the stroke, and one of the legs is no longer of use to propel the engine forward, the other, immediately on the motion of the piston being changed, is ready, in its turn, to act as a fulcrum or abutment for the action of the moving power, to secure the continual progressive motion of the engine.

The feet are raised from the ground during the return of the legs toward the engine, by straps of leather or rope fastened to the legs at *ff*, and passing over friction sheeves, moveable in one direction only, by a ratchet and catch worked by the motion of the engine. The feet are described of various forms in the specification, the great object being to prevent them from injuring the road, and to obtain a firm footing, that no jirks should take place at the return of the stroke, when the action of the engine came upon them; for this purpose they were made broad, with short spikes to lay hold of the ground.

In a communication to the editor of the *Repertory of Arts*, vol. 24, the patentee gives an account of an experiment made with one of those engines, which he termed his mechanical traveller; the boiler was of wrought-iron, five feet six inches long, three feet diameter; the step was twenty-six inches long, the piston-rod having a stroke of twenty-four inches; the

weight of the whole 45 cwt. "The machine being placed on a Rail-way, I first ascertained the power necessary to move it at the rate of two miles and a half in an hour, which I found to be eighty-four pounds. I then applied a chain to the hinder part of the machine, by which, as the machine moved forward, a weight was raised at the same time and rate, and found, that with steam equal to forty or forty-five pounds pressure on the square inch, the machine was propelled at the rate of two miles and a half per hour, and raised perpendicularly 812 lbs. at the same speed, thus making the whole power equal to 896 lbs. at two miles and a half per hour, equal to six horses nearly."

About this time Mr. Blackett had considerably improved his engines, and by experiments had ascertained the quantity of adhesion of the wheels upon the rails, and proved that it was sufficient to effect the loco-motion of the engine upon Rail-roads approaching nearly to a level, or with a moderate inclination. His Rail-road was a plate rail, and would consequently present more friction or resistance to the wheels than an edge-rail; and, on that account, the amount of adhesion would be greater than upon the latter rail; still the credit is due to Mr. Blackett, for proving that the loco-motion could be applied by that means alone.

The first attempt of Messrs. TREVITHICK and VIVIAN failed, and though this was no doubt owing to the imperfect construction of the engine, yet it appears that the cause was partly, if not wholly, attributed to the want of adhesion to obtain loco-motion; and hence we find the engineers attempting to produce other means of loco-motion. Mr. BLENKINSOP, by means of a cog-rail; Mr. CHAPMAN, by the chain; and Mr. BRUNTON, by means of moveable legs.

It was, however, a question of the utmost importance, to ascertain if the adhesion of the wheels of the engine upon the rails were sufficient to produce a progressive motion in the engine, when loaded with a train of carriages, without the aid of any other contrivance; and it was, by the introduction and continued use of them upon the Wylam Rail-road, that this question was decided: and it was proved, that upon Rail-roads nearly level, or with very moderate inclination, the adhesion of the wheels alone was sufficient, in all the different kinds of weather, when the surface of the rails were not covered with snow.

Mr. HEDLEY informs me, that they first tried, by manual labour, how much weight the wheels of a common carriage would overcome without sloping, or slipping ground, upon the rail;

and having found the proportion it bore to the weight, they thence ascertained that the weight of the engine would produce sufficient adhesion to drag after it, upon their Rail-road, a requisite number of waggons.

The first engine applied upon the Wylam Rail-road had only one cylinder, with a fly-wheel to regulate the action of the crank; but they were found to be very troublesome, and their action very uncertain. When the engine was stopped, and the crank and connecting rod in the same line, the power of the cylinder had then no effect in turning the crank round, and the engine had to be moved by levers applied to the spokes of the fly-wheel, until the crank formed such an angle with the connecting road that the engine got sufficient power to produce a rotatory motion and urge itself forward. This occasioned frequent delays, and the irregular action of the single cylinder produced jirks in the machinery, and had a tendency to shake the machine in pieces; for some time, however, the whole of the coals was taken down the Rail-road by the use of this kind of engine.

In the early part of the year 1814, an engine was constructed at Killingworth Colliery, by Mr. George Stephenson, and on the 25th July, 1814, was tried upon that Rail-road. This engine had two cylinders, each eight inches

diameter, and two feet stroke; the boiler was circular, eight feet long, and thirty-four inches diameter; the tube twenty inches diameter, passing through the boiler.

Fig. III. *Plate* IV. will shew the manner by which the power of the engine was communicated to the wheels, and the loco-motion effected. A A are the wheels of the carriage supporting the engine; B B, the frame of the carriage on which the boiler is fixed; *a b* and *c d* are the connecting rods, similar to *b c b c. Fig.* I., transferring the motion from the piston to the crank. *b. c.* and *d f* are the cranks which turn the two small cog-wheels *e f*; the cranks are placed in such a position, with respect to each other, that when one of them is perpendicular, or in a line with the connecting rod, the other is horizontal, and at right angles to it; and this arrangement is continually secured by the interposition of another cog-wheel, of the same size, and working into the other cog-wheels, *e* and *f*.

Two larger cog-wheels, K and K, are fixed upon the axles of the carriage-wheels, which, when the small wheels *e* and *f* are turned round, by the rotatory motion of the crank, are also turned round, and with them the wheels of the engine.

The wheels of the engine being thus turned round upon their axis, the friction of the rim of the wheels against the rails being regulated by the pressure upon them, and preventing the wheels from turning or sliding round upon the rail, would necessarily cause them to roll forwards along the rail, and thus produce a progressive motion in the engine.

If the power required to produce, or the

resistance opposed to the progressive motion of the wheels, were greater than the friction or adhesion of the exterior surface of the periphery of the wheels upon the rail, the wheels would then slide round, and the engine would stand still; but so long as the former does not exceed the latter, the wheels will always roll forward along the rails, and effect the progressive motion of the engine.

In this engine, the small cog-wheels *e g f* were each twelve inches diameter, and the cog-wheels upon the axles of the travelling wheels twenty-four inches diameter; so that the cranks made two revolutions for one revolution of the engine-wheels.

This engine was tried upon the Killingworth Colliery Rail-road, July 27, 1814, upon a piece of road with the edge-rail, ascending about one yard in four hundred and fifty, to draw after it, exclusive of its own weight, eight loaded carriages, weighing altogether about thirty tons, at the rate of four miles an hour; and, after that time, continued regularly at work.

The application of the two cylinders rendered the action of the engine regular, and secured the continual progressive motion; thus remedying the imperfection caused by the irregular action of the single cylinder and fly-wheel.

When the engine had been at work a short time, it was soon found that sufficient adhesion existed upon the edge-rail to perform the requisite traction to the load; at first, grooved sheeves were fixed upon the hinder travelling wheels of the engine, and similar grooved sheeves upon the fore-wheels of the convoy-carriage containing the coals and water, with an endless chain working over each, to procure the adhesion of the wheels of the convoy-carriage, in addition to the adhesion of the engine-wheels; but, on trial, it was not found necessary to resort to the aid of this contrivance, as the adhesion of the engine-wheels alone was found sufficiently adequate to produce the desired effect.

The communication of the pressure upon the piston, through the means of the crank to the cog-wheels, produced great noise, and, in some parts of the stroke considerable jerks; each cylinder alternately propelling or becoming propelled by the other, as the pressure of the one upon the wheels became greater or less than the pressure of the other, and this, when the teeth became at all worn, caused a rattling noise; for, when the leverage of the one crank became greater than the other, the latter was propelled by the other through the intervening wheels; but when the former

approached towards the extremity of the stroke, its leverage became less and less, and the leverage of the latter became greater as the angle between the connecting rod and the crank increased; and, at a certain point, the latter preponderated. When a change in the action took place, the former was propelled, and the latter was the propelling power. If any play or space existed between each tooth of the cog-wheels, the transition of this power from one side of the teeth to the other, always occasioned a jerk; and this became greater as the teeth became more worn, and the space between each other greater.

To obviate this became desirable, and Mr. Stephenson, in conjunction with Mr. Dodd, took out a patent for a method of communicating the power of the engine directly to the wheels without the aid of these cog-wheels. The patent was dated Feb. 28, 1815, and consisted of the application of a pin upon one of the spokes of the wheels that supported the engine, by which it travelled upon the Rail-road, the lower end of the connecting rod being attached to it by what is termed a ball and socket joint; the other end of the connecting rod being attached to the cross-beam, worked up and down by the piston.

a b, *Fig.* IV. *Plate* IV. represents the connecting rod,

the end *a* attached to the cross-beam, and the end *b* to one of the spokes of the wheel; in like manner the end *d* of the connecting rod *c d*, is attached to the beam of the other piston, and *h* and *c* to a pin fixed in the spokes of the wheel B. By these means, the reciprocating motion of the piston and connecting rod is converted by the pin upon the spokes acting as a crank into a rotatory motion, and the continuation of this motion secured by the one pin or crank being kept at right angles to the other, as shewn in the drawing.

To effect this, the patentees had two methods, to crank the axle on which each of the wheels were fixed, with a connecting coat between, to keep them always at the angle, with respect to each other; or to use a peculiar sort of endless chain, passing over a toothed wheel, *Fig.* V. on each axle. This endless chain, which is now solely used upon these kind of engines, consisted at first of one broad and two narrow links, alternately, fastened together at the ends with bolts; the two narrow links were always on the outside of the broad link; consequently, the distance they were separated laterally would be equal to the breadth of the broad link, which was generally about two inches, and their length three inches. The periphery of the wheels, fixed upon the axles of the engine, were furnished with cogs, projecting from the rim of the wheels, (otherwise perfectly circular and flat) about an inch or

one and a half inches. When the wheel turned round, these projecting cogs entered between the two narrow links, having a broad link between every two cogs, resting on the rim of the wheel; these cogs, or projections, caused the chain to move round with the wheel, and completely prevented it from slipping round upon the rim. When, therefore, this chain was laid upon these two toothed wheels, one wheel could not be moved round without the other moving round at the same time with it; and thus secured the proper angles to the two cranks.

This mode of communicating the action of the engine, from one wheel to another, is shewn in the drawing of *Fig.* IV. *Plate* IV; the wheels A and B having each projecting cog-wheels, round which the endless chain passes. This contrivance entirely superseded the use of the cog-wheels, and were without the jolts or jerks incident to them; for, when the chain got worn by frequent use, or was stretched, so as to become too long, one of the chains of the axles could be moved back to tighten it again, until a link could be taken out, when the chain was moved back again to its former situation.

An engine of this construction was tried upon the Killingworth Rail-road, on March

6th, 1815, and found to work remarkably well.

The next improvement by Mr. Stephenson, was part of the subject of the patent of Messrs. Losh and Stephenson, so often mentioned previously, respecting the improvement in the rails and wheels. Considering, in general, the disappointments met with in the eventual utility of most of the patents, this appears a rare instance to the contrary; more general benefit has been derived from the different contrivances, exhibited in this patent, than in any other on the subject of Rail-road conveyance; and, indeed, than many on any other subjects, and certainly confer great credit upon the patentees. The contrivance is very minutely described, in the specification of their patent; and the advantage derived is very judiciously and very clearly stated; I shall give it in their own words:—

"In what relates to the locomotive engines, our invention consists in sustaining the weight, or a proportion of the weight, of the engine upon pistons, moveable within cylinders, into which the steam or water of the boiler is allowed to enter, in order to press upon such pistons; and which pistons are, by the intervention of certain levers and connecting rods, or by any other effective contrivance, made to

bear upon the axles of the wheels of the carriage, upon which the engine rests.

e e e Fig. IV. *Plate* IV. shew the cylinders placed within the boiler, one side of which, in the drawing, is supposed to be removed, to expose them to view. They are screwed by flanches to one side of the boiler, and project within it a few inches; and are open, at the top, to the steam or water in the boiler; *g g g* are solid pistons, filling the interior of the cylinders, and packed in the common way to render them steam-tight. The cylinders in the figure are drawn as cut through the middle, to shew the pistons. The cylinder is, also, open at the bottom, and is screwed upon the frame of the engine, as represented at *a a*, *Fig.* II. *Plate* V. The pistons are furnished with a rod, in a similar way to other pistons, inverted and securely fixed to it; the lower end of which passes through a hole in the frame which supports the engine, and presses upon the chain which rests on the axis of the wheels on which the carriage moves. The chain has liberty to move up and down with the piston-rod. When, therefore, the steam presses upon the piston, the weight is transmitted to the axle by the piston-rod, and the re-action of that pressure takes as much weight off the engine. If, therefore, the cylinders are of sufficient area, so that the pressure of the steam upon the whole of the pistons is equal to the weight of the engine, the engine will be lifted up, as it were, or entirely supported by the steam, which thus forms a kind of spring of the nicest elasticity.

The weight of the engine forming one great obstacle to its introduction where the rails were weak, it was of the utmost importance to find out some remedy. Mr. Chapman, in his

patent for the application of a chain, described a plan of placing the weight of the engine upon two frames, supported by six or eight wheels: and the Wylam engines, being heavier than the rails would bear, were placed upon eight wheels; but the complication attendant on so many wheels, and the unwieldy nature of such a length of framing, formed altogether so many objections, as to render them almost useless, as a species of moving power.

The application of the steam-bearing cylinders divided the weight equally upon the four wheels, and, if necessary, upon six wheels, as shewn in *Fig*. IV. *Plate* IV., and thus caused one frame to be sufficient, and, consequently, simplified their construction proportionably.

Having thus given a sort of historical account of the introduction of the loco-motive engine, its gradual and successive improvements, and, in doing so, described many of the detached parts entering into its construction, I shall now proceed to describe the whole combined, as forming the engine at present in use upon the Killingsworth Rail-road.

Fig. I. and II. *Plate* V. represent a side and end view of one of the engines used upon the Killingsworth Rail-road, with its convoy-carriage, and a portion of a waggon, being a part of the train of carriages constituting its load.

The boiler is of malleable iron, cylindrical with hemispherical ends. A cylindrical tube passes through the boiler, within two inches of the bottom; in one end of the tube the fire is put, and the other end is terminated by a chimney. The grate, whereon the fire is laid, is placed rather below the middle of the tube, and reaches about four feet within it, resting at the further end, upon a narrow partition of brick, closing up the lower side of the tube below the bars. F, *Fig.* II. shews the fire door, which, at the tube end of the fire, closes up the upper side of the tube, thus forcing the air through the fire in the usual manner. The boiler rests upon a square frame of malleable iron, supported by the steam cylinders *a a*, previously described, two on each side, seven inches diameter; the cylinders are partly placed within the boiler, as shewn in the drawing, and are nine inches diameter, and lined on the inside with sheet copper; the piston-rods work through stuffing boxes, in the usual way, and are attached to the cross-beams B B and C C, sometimes formed of one piece, and sometimes of more than one, as represented in *Fig.* II. The rectilinear motion of the piston-rod is secured by the slides *s s s s*, fastened to the projecting arms *c c*, cast upon the top of the cylinder, and kept perpendicular by the braces *b b*.

The connecting rods D D and C D are fixed upon the ends of the cross-beams by ball and socket joints; and, at the other end, by similar joints, to a pin fixed in one of the spokes of the engine-wheels, at D D; to strengthen this spoke, a circular piece of metal attaches the two adjoining spokes with it.

The wheels, as shewn in the drawing, are four feet diameter, and are made of cast-iron with circular naves, rimmed out to fit the axle, and fastened to it by means of iron keys.

The axles are of wrought-iron, about three inches and

a half diameter, and are turned perfectly round at each end, where the chair comes upon, and also at the extreme end where they pass into, the nave of the wheel.

The chairs, on which the engine rests upon the axles, are made of brass, four inches broad, and reach to the semi-circumference of the axle; as before explained, they are at liberty to move up and down, to conform with the inequalities of the road: two of these chairs are fixed upon the frame of the carriage, and the other two are moved backwards and forwards by a sliding groove upon the frame, to keep the chair sufficiently tight.

The frame is made of wrought-iron, welded together: on this the bearing cylinders are fastened by bolts, with a joint perfectly steam-tight.

The steam is communicated, from the boiler to the cylinders, through a passage, the area of which is regulated by the sliding lever, or handle, c *Fig.* I. which, of course, restricts the quantity, and regulates the velocity of the engine. The steam is admitted to the top and bottom of the piston, by means of a sliding valve; which, being moved up and down alternately, opens a communication between the top or bottom of the cylinder and the pipe *d d*, that is open into the chimney, and turns up within it.

The steam, after performing its office within the cylinder, is thus thrown into the chimney; and the power with which it issues will be proportionate to the degree of elasticity; and the exit being directed upwards, accelerates the velocity of the current of heated air accordingly.

The action of the steam-engine is now so well known, that it will not be necessary

to describe the mode by which the rectilinear motion of the piston is converted into the rotatory one of the wheels, and the progressive motion of the carriage thereby affected: a slight inspection of the drawing will convey to those who have the slightest knowledge of machinery, the manner in which it is done, as nothing can be more simple and effective.

The sliding, or steam valve, is opened and shut, at the proper periods, by the following contrivance; *a*, *Fig.* V. *Plate* IV., represents the axle of the travelling wheels of the carriage; *a b* is a lever fastened upon, and turning round, at the same time with it; *b c* is a circular opening in the eccentric circle *d e*, within which a pin, attached to the end of the lever *a b*, is at liberty to move; this eccentric circle is loose upon the axle of the carriage, and is only turned round when the pin, at the end of the lever *a b*, arrives at *b a c*, according to the direction in which it is moving; a circular hoop, or strap of iron, fits the circumference of the eccentric motion, connected to the lever *f g h*, which is moved backwards and forwards as the axle turns round; as this lever is moved, its motion is communicated to the arm *i k*, as shewn in *Fig.* I. *Plate* V. also, and through it, by the lever *k l* and rod *l m*, to the cross-head *m n*, and so to the rod *n o*, of the sliding or steam valve, which, as the carriage is moved forward, is thus slided up and down to open and shut the communication between the two sides of the cylinder and the boiler, at the proper periods.

Before the application of this mode the measure was effected by a square box or tumbler. It seemed to me, from the irregularity of the

noise, caused by the exit of the steam into the atmosphere, that the changes were not made at the proper time of stroke, and I applied this as a sort of experimental plan, by which, on altering the screws *h* and *i*, the steam could be thrown into the cylinder at any time of stroke. I soon found that there was a certain time, at which the opening into the cylinder should be made, when the effect was the greatest; and, as the common tumbler did not effect this at the same period of stroke when the carriage was moved in both directions, I retained this mode of working the slides permanently.

p is the man-hole door, to have access into the interior of the boiler; *v* is the safety-valve, to allow the steam to escape, when the elasticity becomes too great. It is loaded with the weight W, corresponding with the pressure of steam, which it is found requisite to retain within the boiler.

The boiler is supplied with water by means of a small forcing-pump, P, fixed to the side of the boiler, and worked by the rod *r*, attached to the cross-beam of the engine. The diameter of this pump is very small, so that the quantity of water injected shall not reduce the temperature of steam in the boiler, so as to be injurious, and prevent the regular supply of steam to the cylinder. The quantity of water

required not being great, it is pumped in at proper intervals, when the draught is easy, and when the pressure, for the load of steam, is not required to be very great.

When the engine is used for travelling, the boiler is inclosed within a wooden covering, consisting of thin narrow deals, to prevent the radiation of heat; when this is not done, the wind has great effect in reducing the temperature, by the rapid abstraction of heat.

The water and coals, required for the regular wants of the engine, are carried in the convoy-carriage Y, attached to the engine. The size of this, and the quantity carried, will, of course, depend upon the length of the stages the engine has to travel, or the convenience of obtaining them.

The train of carriages moved by the engine is most frequently attached to the convoy-carriage; but the engine can, also, drive the carriages in the front, by propelling them forward; but this is very liable to drive the carriages from off the road, especially when turns or curves in the line of the road occur.

The endless chain, for keeping the cranks of the engine in the proper angles, with respect to each other, are different from those previously described. Those, in this engine, are formed alternately of a circular and a flat link;

by examining the drawing, *Fig*. I. II., it will be seen that the teeth, or projections of the wheel, protrude themselves within the flat links, while the round links fall into circular cavities between the teeth. The advantage of this form of chain is, that the circular links are at liberty to move round, and thus present a different surface to the teeth of the wheel, so as to equalize the wear. Many plans have been devised to obviate the use of this chain, but nothing superior has yet been devised. The friction is comparatively trifling; the links, falling as it were into their places without sliding, occasions little wear, and, consequently, produces little friction. The proper length, as before stated, is effected by the removal of one chair, or one of the pair of wheels further from the other, by which the chain is tightened, until it admits of a link being removed, when the wheels are again brought to their former situation.

The locomotion of this engine, as will be perceived, is effected by the action of the wheels upon the rail, without the aid of any extraneous mechanism, and consists of the hold or adhesion of the surface of the wheels, against the surface of the rail. The rationale of the action will be very evident, by an inspection of the drawing; the power of the steam in the

cylinders is employed to turn the wheels of the engine round, by a pin fixed in one of the spokes of the wheel, and acting as a common crank; these wheels, resting on the rail, press upon them with a force equal to the weight of the engine, divided into the number of wheels; thus, suppose there are four wheels, then the pressure of the periphery of each wheel, upon the surface of the rail, is equal to one-fourth of the weight of the engine. Now it is well known, that when two surfaces are in contact, and subjected to a certain pressure, it requires a certain force to cause them to slide upon each other; that property, in bodies, to resist sliding, is called adhesion of the surfaces. Suppose, then, the power of the cylinders be employed to turn the wheels of the engine round, this property of bodies, in contact, will prevent the wheels of the engine from sliding upon the rail, with a force equal to their weight or pressure, and they will necessarily roll along the surface. If, however, the progressive motion be opposed to a retarding force, greater than the force or power of adhesion, then the surfaces will slide upon each other; and the rotatory motion of the wheels will be continued without effecting a progressive motion of the engine.

The power by which the engine propels

itself forward, or by which the progressive motion of the engine is effected, is, therefore, the adhesion of the surface of the wheels upon the rail; and the reader will perceive that this power is acquired without in the least affecting or adding to the resistance. The resistance, or friction of the wheels upon the rail, would be the same upon the wheels of any other carriage, of the same weight, as upon the wheels of the engine when propelling itself forward; and this is not mere supposition, for, in comparing the space passed over by the engine, with a given number of revolutions of the wheels, no sensible distance was lost, which proved that no sliding took place.

By knowing the amount of adhesion upon surfaces, in contact with each other, we might deduce the power of adhesion presented by the rail to the wheels of the engine, and this would be the power required to cause the engine to slide along upon the rail, supposing the wheels were prevented from turning round. This, however, is by no means constant; at one time the rails are quite dry, at another quite wet, at other times partly both, and sometimes slightly covered with a film of mud; in all of which cases the amount of adhesion varies; to deduce to any data of practical utility, we must, therefore, ascertain the amount

in all the different states of the weather; I shall afterwards give an account of some experiments made to ascertain this point.

From the nature of this kind of motive power, it will occur to the reader, that the ascent in the line of road must never be such as will present a resistance to the engine, equal in amount to the adhesion of its wheels upon the rail; the limits of their action will, therefore, be within certain lines of road, nearly approaching to a level, or receding little from it. When the amount of adhesion shall have been ascertained, we will be able to fix this limit.

Since writing the foregoing, I have been favored with a drawing of one of the engines, at present used upon the Wylam colliery Rail-road, previously noticed; which, as its construction is different from the Killingsworth engines, and adapted for a plate Rail-way, and being, also, supported by eight wheels, thinking a plan of it might be useful, I have made a plate of it on a larger scale.

Plate VI. will shew a side-view of this engine; B represents the boiler, which is circular, with one hemispherical and one flat end. The tube in this boiler does not pass directly through and terminate at the chimney, as shewn in the other engines, but passes from the end *a* to the end *b* of the boiler, and then returns back again to the chimney, at the end *a*, thus forming a double tube in the interior

of the boiler. The fuel is put in at the end *a*, and *f* shews the depôt containing the coals, constituting the supply for one trip or journey.

c is one of the cylinders affixed to the side of the boiler; immediately opposite to which, on the other side of the boiler, the other cylinder is placed. A A are two beams, fixed at one end D, upon the upright frame E E. The other ends moveable up and down, by means of the piston-rod F; the rectilinear motion, within the cylinder, is effected by the parallel motion P P, in the usual manner. The cylinder, as shewn in the drawing, is cased with wood, to prevent the radiation of heat from its exposure to the air. G G is a square frame of wood, on which the boiler is supported, and which is itself supported by the upright transverse bearings K K upon the two separate frames H H and I I. The upright bearings, K K, are placed across the square frames, exactly in the middle, so that each of the respective pairs of wheels, on which they rest, bear equal portions of the weight. The transverse supports, K K, are fastened to each of the frames H H and I I, by bolts in the middle, which allow a lateral motion in the frames, to conform with the occurrence of curvitures in the line of the road. Underneath the frame G G, and stretching across it from one side to the other, an axle, N, is placed, upon which, at each end, the two cranks are fixed; N M will shew one attached to the connecting rod L M, moveable upon the beam at L. These two cranks are placed upon the axle at right angles to each other, so that, when one is perpendicular the other is horizontal; thus securing the constant action of either one or other of the cylinders upon the axle, to effect its rotatory motion.

Upon the middle of the axle on which the cranks are placed, the continual roratory motion of which is kept up by the engine, a cog-wheel is fixed, as shewn in the

drawing, which is, consequently, turned round, and partakes of the motion of the crank-axle. This wheel works into another immediately underneath it, which last again works into one on each side, and these again into others, as represented in the figure; and thus the rotatory motion is communicated to the carriage-wheels, which, by the adhesion of their peripheries upon the rails, effects the progressive motion of the whole.

W shews the cask containing the water, to afford a regular supply to the boiler, which is pumped into the boiler in the same manner as explained in the other engines.

After the steam has performed its office in the cylinders, it is allowed to escape into the pipe *r*, communicating with the circular reservoir S, into which it expands, and then makes its exit into the chimney by the pipe *r'*.

The action of this machine will readily be understood by an inspection of the drawing: in principle, it does not differ from those shewn in *Plate* V. the progressive motion of both being effected by the adhesion of the travelling wheel upon the rail. The mode of working the beams differ, and also the way of communicating the motion and power of the engine to the wheels; the Rail-road on which these engines travel, being too weak to support the weight divided on four wheels, recourse was obliged to be made to eight wheels; and this rendered the use of so many cog-wheels necessary, to obtain the adhesion of the whole weight of the engine.

This circumstance adds much to the complication of the engine, which, of course, increases the friction by the multiplicity of cog-wheels and other moving parts. When the Rail-road is sufficiently strong, the construction of an engine, to travel upon the plate-rail, need not be varied necessarily, except in the form of the rim of the wheels, to suit the surface of the rails.

CHAPTER V.

ACCOUNT OF EXPERIMENTS ON THE STRENGTH OF CAST AND MALLEABLE IRON-RAILS.

Cast-iron, since it superseded the use of wooden-rails, has been most extensively used in the construction of Rail-road. As usual in like cases, at its first introduction, considerable opposition was made to its use—its brittleness and liability to break—its cutting the wheels, when in the form of edge-rails, and several other objections, were urged against it; time and experience have, however, confirmed its utility, and extirpated those prejudices. Though its nature renders it liable

to break, when subjected to sudden blows, and its strength is considerably affected by the unavoidable occurrence of air-bubbles, and other imperfections in its organization; yet still we are enabled to form a Rail-road with it, on which weights of considerable magnitude can be conveyed, without much risk of breakage.

It is a consideration of paramount importance, in the construction of a Rail-road, to form it of such materials as combine strength and durability with economy. Cast-iron, while its hardness presents a surface that opposes little obstruction to the wheels of the carriages, forms a substance which is also very durable, and resists the action of the wheels with great effect. Its brittleness forms the only source of reasonable objection; and, as that cannot be obviated without increasing the section of the rail, and adding to the weight, and consequently to the cost, has lately produced an innovation in the material, in the substitution of a particular form of malleable iron-rails, the tenacity of which resisting sudden fracture, therefore obviates the danger, inconvenience, and cost of the breakage of cast-iron.

In describing the different kind of rails, used in the construction of Rail-roads, I have

previously given the opinion of some engineers on the comparative merits of cast and malleable iron-rails; there is, however, a great deal yet wanting, in a practical point of view, more than mere opinion. There are wanting experiments to prove the different properties—their strength, durability, and the resistance to the carriages moved along them. It has been my wish to supply that defect, so far as the opportunities within my reach have enabled me; I regret to say, however, that my investigations have, as yet, not reached beyond the first, at least in the shape of experiment. The ultimate wear will require time to elucidate; and I have not yet had an opportunity of ascertaining the comparative resistance of carriages moved along them. I shall, therefore, at present confine myself to their relative strength, as ascertained by experiments.

The most general form of the edge-rail is that of a parabola on the under side, the upper side being quite straight. The attention of mathematicians has not been much occupied in this particular case, or in demonstrating the strongest form of section when the weight is rolled along the surface. When the beam is supported at each end, as is the case with a rail, and loaded in the middle,

the upper being quite straight, the line, bounding the under side in the form of section, usually considered the strongest, is that of two semi-parabolas, the vertex being the point where the force acts; but, in the case of a weight rolled along the Rail-road, the pressure is occasionally acting throughout the whole length. On that account, perhaps, the line bounding the under side should be that which presents the greatest strength, when the beam is supported at each end, and loaded equally throughout the whole length, which is a semi-ellipse.

The want of a practical treatise on the strength of cast-iron, and on the various forms of section, suitable for beams, acted upon in different ways, was, until lately, very much felt. Mr. Tredgold has, in his treatise on the strength of cast-iron, supplied that want, and given numerous practical examples on the subjects. The reader, who wishes to inform himself further on the subject, will find some very useful information in that work.

Account of some Experiments made at Walker Foundery, near Newcastle-upon-Tyne, the property of Messrs. LOSH, WILSON, *and* BELL, *on the strength of cast-iron rails.*

The rails were all cast from the same pattern, the difference in weight being accidental. Section similar to *Fig.* I. and III., *Plate* II., two inches and a quarter broad on the upper side, and tapering away to one inch and a half in the middle, and again swelling out at the bottom into the square *c, b,* each side of which is seven-eighths of an inch. Extreme depth, in the centre, six inches, gradually decreasing towards the ends, or points of supports, in a parabolic form, to four inches. In the experiments the rails were fastened in the usual manner to the chairs, which were fixed upon beams of wood.

EXPERIMENT I.

Number of Experiments.	Description of metal.	Wgt. of each rail. lbs oz	Weight which produced fracture. cwts qrs lbs	Average wgt. of each kind of rails. lbs oz	Average strength of each kind of rails. cwts qrs lbs.	Relative strength of mixed and unmixed metal, specific gravity considered.
1	No. 1, metal A...	56 6	126 3 0	55 9	114 1 14	146 122
2	—— Ditto.....	56 0	99 3 0			
3	—— Ditto.....	55 8	108 3 0			
4	—— Ditto.....	54 7	122 1 0			
5	No. 1, A, same kind as preceding mixed with old metal	58 14	148 2 0	59 10	146 0 14	
6		58 9	144 0 0			
7	No. 1, metal B...	55 10	113 1 0	56 6	106 2 0	156 108
8	—— Ditto.....	57 1	99 3 0			
9	No. 1. B, mixed	57 13	162 3 0	57 10	156 0 0	
10	with old metal	57 7	149 1 0			
11	No. 1, metal C....	55 8	150 3 0	55 4	140 2 14	173 128
12	—— Ditto.....	55 0	130 2 0			
13	No. 1, C, mixed..	56 4	184 2 0	56 10	173 3 0	
14	—— Ditto.....	57 0	162 0 0			
15	No. 1, metal D...	56 3	113 1 0	56 2	115 2 0	194 119
16	—— Ditto.....	56 1	117 3 0			
17	No. 1, D, mixed	59 9	207 3 0	58 4	194 1 0	
18	with old metal	56 14	180 3 0			
19	No. 2, ditto D....	56 13	95 1 0	56 5	97 2 0	
20	—— Ditto.....	55 12	99 3 0			
21	No. 3, ditto D....	57 13	104 1 0	57 5	108 3 0	
22	—— Ditto.....	56 14	113 1 0			
23	No. 1, metal E...	56 6	128 1 0	56 12	131 2 14	137 144
24	—— Ditto.....	57 2	135 0 0			
25	No. 1, E, mixed	55 6	148 2 0	55 8	137 2 0	
26	with old metal	55 10	126 0 0			
27	Rail cast-iron different kinds of metal, close fracture......	55 8	135 3 0			
28	Do. open fracture	57 1	99 3 0			
29	Rail 4 feet long..	58 0	120 0 14			
30	—— 3 ft. long, No. 2, metal	33 0	98 2 14			
31	—— 3 ft. Welsh metal........	33 0	100 3 14			
32	—— 3 ft. No. 1, metal........	33 0	107 2 14			

In comparing the strength of the different rails with each other, we find a great variation, not only between the different kinds of metal, but also in rails cast from the same metal. The only constant and regular law appears to be, that the weight, or specific gravity of rails, formed of a mixture of different kinds of metal, is uniformly greater than of one description of metal separately, and also that such a mixture makes the rails invariably stronger. This is a very useful discovery, and enables the founder, by mixing different metals in the proper proportions, to form a rail much stronger with the same weight of metal, than could otherwise be done by casting them of any particular kind of metal alone.

The depth of the middle section of the cast-iron rail renders them very rigid, and the deflexion is comparatively trifling before fracture. The recorded weights are those which produced fracture. In loading the rails, the weights should of course be much less than that which breaks the rail; inequalities of the road, or occasional obstacles occurring upon the surfaces of the rails will sometimes produce jerks or shocks to the wheels of the carriages, and the re-action will transfer those to the rail, and cause blows which, from the brittleness of the material, will be very liable to produce

fracture. In the form of carriages, too, placed upon four wheels, the weight upon any one of these wheels is far from being regular. The frame of the carriage is necessarily made square, and the sides quite parallel to each other, and are kept permanently so by the sides being firmly bolted or fastened together. The bearing section of the wheels is, therefore, perfectly square and parallel: when the road is not similarly square and parallel, (and which, in practice, is seldom or never the case,) the weight of the carriage will be frequently, if not always resting upon three wheels only; and, in many instances, when a change in the parallelism of the rails takes place, upon two, on opposite sides of the carriage, the transition of the weight from one wheel to another will, therefore, produce a continual succession of blows or shocks to the rails, which will be productive of considerable injury, and occasion frequent breakage.

From these causes, and others which it is not necessary to mention, we find that it is not practicable to subject the rails to a greater load than is considerably within the limit of their absolute strength. In the preceding experiments, the least weight of the rails formed of a mixture of metals is seven tons, and of the unmixed rails five tons; and the rails were of the

size and weight for a Rail-road, on which the carriages that passed upon it were intended to be four tons, supported upon four wheels.

In extreme cases, when the inequalities of the road throws the weight from one wheel to another, the greatest strain upon any one rail cannot amount to more than two tons; therefore, the proportion which the load that can be carried with perfect safety bears to the absolute strength of the rails, is, in the one case, 3.5 : 1, and, in the other, 2.5 : 1, but, as it may be supposed that a mixture of metals will be mostly used, we may, in practice say, *that the strain to which the rails of any Rail-road should be subjected by the load, ought not to amount to more than about one-third of their absolute strength, or of that weight which would produce fracture.*

This will force a rule sufficiently accurate for practice, and being easily comprehended by any one, will, I trust, be found useful. I shall now give some experiments made on the strength and flexibility of malleable iron-rails.

Account of some Experiments on the strength and flexure of malleable iron-rails, made at Bedlington Iron-works, Dec. 6th, 1824.

Section of rail similar to *Fig*. IV. and V. *Plate* II.; distance between the supports three feet; depth in the middle $3\frac{7}{16}$ inches, tapering away, at each end, to $2\frac{1}{4}$ inches; breadth at top $2\frac{1}{4}$ inches; thickness about $\frac{5}{8}$-ths of an inch; weight per yard 28 lbs.

The rail was nine feet long, fastened to the chairs three feet a part, in the same way as in forming the road; the rail was inverted, and the extreme ends rested upon two blocks of timber, the direction of the strain being upwards, and applied at the middle of the bearing.

The rail was made of scrap-iron, and taken promiscuously out of a heap of rails intended for the Darlington Rail-road.

EXPERIMENT II.

Weight in cwts.	Deflexion in inches.	REMARKS.
28 56 84 112 126	.06 .11 .2 .35 .47	On the weight being removed it immediately resumed its original form; and to ascertain if any injury had taken place, the following experiments were made.
28 126	.11 .47	When the weights were taken off, the bar again returned to its original form; the weights were then replaced, and the successive deflexions corresponded with the respective weights as in the former experiment.
131·5	.57	When unloaded it came back to its original form.
56 126 140	.115 .48 .63	The weights were again applied, and the respective deflections found as described; the weights were allowed to remain on for some time, and, on being removed, a permanent deflexion had taken place of .0035 inches.
154	.92	On the weights being again added, the deflexions were nearly similar to those previously observed. When loaded with 154 cwt. the deflexion was found as stated; the weights were then removed, and it was found that the bar had acquired a permanent bend of .24 inches. The rail did not appear otherwise injured.

EXPERIMENT III.

Rail, three feet long, merely laid upon the supports, without being fastened.
Was loaded with 112 cwt., and, on the weights being removed, it returned to its original form. The weights were again laid on, and, also, an additional quantity, amounting to 127¾ cwts. which, when taken off, the bar again came to its original shape. It was then loaded with 140 cwt. which, on being removed, was found to have given a permanent deflexion of .25 inches.

The reason of the variation, in the mode of subjecting the bar to the strain, was to ascertain the difference in strength between rails merely laid upon, and those fastened to, the supports. The superiority is in favor of those fastened to the supports, which shews the advantage of long bars, and, consequently, of forming the malleable iron-rails into long lengths.

The limit of permanent elasticity, in this kind of malleable iron-rail, appears to be about six tons; but, when loaded with this weight, the deflection, in the middle, amounted to nearly half an inch. This rail is made to carry the same load as the cast-iron rails previously described; the extent of the strain by the carriages will, therefore, be two tons, which will produce a deflexion of about one-ninth or one-tenth of an inch.

The limit of permanent elasticity in this rail, as will be observed, is nearly equal to the limit of absolute strength in the cast-iron; but the former, from the nature of the material, may be loaded much nearer the limit of its permanent elasticity than the latter may, with regard to its greatest strength.

CHAPTER VI.

EXPERIMENTS MADE ON THE FRICTION AND RESISTANCE OF CARRIAGES MOVED ALONG RAIL-ROADS.

In all carriages, moved along rail-ways, or other roads, there is always a certain obstruction or resistance to their progressive motion upon the road, arising from the attrition of their rubbing parts, and the acting of the wheels upon the road; and this retardation is denominated the friction of the carriages, and which will be greater or less in proportion to the extent of rubbing action compared with the weight of the body.

The resistance opposed to the motion of all wheel-carriages is distinguishable into two separate causes—That arising from the pressure or attrition upon the axles, and that of the obstruction to the rolling of the wheels upon the rails.

In the case of a common sledge, or a body dragged along the surface of a plane, the whole weight of the body is exposed to attrition, throughout the total length of the plane; the velocity of the rubbing parts being equal

to the progressive motion of the body. On the contrary, if the body be cylindrical, and be rolled along the plane, no part of it is subjected to the action of attrition, the only resistance being that produced by the rolling motion of the periphery upon the plane; which, when the surfaces are smooth and hard, is very trifling.

Suppose now a cylinder, instead of being uniformly solid, to be composed of a number of concentric circles or cylinders, one within another; if this body be rolled along the plane, upon the periphery of the exterior or outer cylinder, the velocities of the peripheries of the respective cylinders, around the centres, will be in the ratio of their diameters. Let the interior cylinder, or that nearest the centre of motion, be of finite diameter; then, if we cause the cylinder to roll along the plane upon the periphery of the exterior cylinder, and place the body or carriage to be moved upon the periphery of the inner cylinder, the velocity of the rubbing surface, or extent of attrition, compared with the extent of rolling surface, or progressive motion of the body, will be in the ratio of the diameter of the inner to that of the exterior cylinder. In all wheel-carriages, therefore, the interior cylinder represents the axles, and

he exterior the wheels of the carriages, and he extent of rubbing surface; and, of course, the friction of the carriage is diminished in proportion to the difference of the size of the axles compared with that of the wheels.

It follows from this, that the extent of rubbing surface, and consequently the friction of that part of the carriages moved upon Rail-ways, which arises from the attrition upon the axles, will be in the inverse ratio of the diameter of the wheels to the axles. The extent of rolling surface, arising from the action of the wheels upon the rails, will always be the same whatever be the diameter of the wheels; but, as large wheels more easily surmount obstacles presented to them than wheels of small diameters, the former will always be preferable, as also diminishing the obstacles to their progressive motion.

Whenever two causes combine in producing a certain effect, unless we can subject them separately to the test of experiment, it is difficult to distinguish how much belongs to one, and how much to the other; and this is the case in the present instance; it would be highly desirable, and no doubt productive of great benefit in practice, to know the amount of friction of the axle, and the resistance of the wheels upon the rail separately; it might

lead to essential service in the formation of the road; and, perhaps, be of great utility in ascertaining the proper force of carriages. It is, however, to be regretted that no experiments have yet been made to ascertain the requisite information.

In constructing wheel-carriages, with a view of diminishing their friction, it would appear that we should make the diameter of the wheels as large, and the axles as small as possible; but there is a limit to this, independent of the inconvenience, in loading and unloading carriages, so much elevated, by being placed upon very high wheels; the axles must be made sufficiently strong to support the weight placed upon them, and that strength is, in a great measure, regulated by the size of the wheels, for the larger the wheels the greater the leverage to twist and break the axles; but, as the tendency to break the axles increases only in the direct proportion of the diameter of the wheels, while the strength of the axles increases in the cube of the diameter, it will, in all cases, be of advantage to make the wheels as large as circumstances will permit.

In all rubbing surfaces there must be a certain proportion between the pressure, or weight of the body, and the extent or area

of rubbing surface, when the friction is a minimum; for, if the bearing be extremely narrow, the surface in contact with it will be cut; and if, on the contrary, it be very broad, an unnecessary extent is exposed. The precise proportion can only be ascertained by experiment, and it would certainly be conferring a great boon to science, were that determined by a set of experiments upon a large scale. Whatever be the ratio of the size of the bearing to the weight of the body, the friction, upon similar bearings, will always bear a determinate proportion to the entire weight of the body.

There are other species of obstruction presented to the motion of carriages, besides those already enumerated, such as the action of the wind, &c.; but as their effects, in retarding the motion, are comparatively trivial, at moderate velocities, or at that rate of speed at which carriages usually travel, we may, in general, omit noticing their effect.

It has been a matter of just regret that so few experiments have been made to ascertain the degree of resistance arising from friction to carriages moved along Rail-roads; on a subject of such importance it is astonishing that, until lately, so little interest should have been excited, comprehending, as it were,

the entire basis of the subject. Observations have been made on the weight a horse could overcome, when placed upon a carriage on a Rail-road; but as we had no measure of the force exerted by the horse, the resistance of the carriage could not be thereby ascertained.

Mr. GRIMSHAW, of Sunderland, when proprietor of a colliery in that neighbourhood, made a great many experiments on the friction of wheel-carriages, with the particulars of which I have been favored. He laid a cast-iron rail-way down, upon beams of wood, and placed upon this rail-way the carriages used by him in conveying his coals down to the river. He then elevated those beams at one end until they formed different angles with the horizon, and observed the time the carriages were in descending from one end to the other, when the plane was elevated to different angles. By comparing the spaces actually passed over by the carriage, with the space which gravity would have caused the body to describe, in the same time, when falling freely, the amount of retardation caused by the friction was thus ascertained.

The result was as follows:—

Loaded carriage, weighing altogether 8522 lbs. friction equal to 50 lbs., or the 170th part of its weight.

Empty carriage, weighing 2586 lbs., friction 10 lbs., or the 258th part of its weight.

Mr. PALMER, in the description of his Rail-road, states the result of some experiments made on the friction of carriages moved along different kinds of Rail-roads. He makes the resistance considerably greater than Mr. GRIMSHAW, amounting to the eighty-seventh part of the weight, as found upon the Edge Rail-road, from the Penryn slate-quarries; but, as this must have been owing to some difference in the construction of the rail-way; and, as Mr. PALMER does not give any detail of his experiments, we are not, therefore, capable of judging of the cause of such an anamoly.

Impressed with the importance of knowing the precise amount of resistance opposed to the motion of carriages along Rail-roads, and, also, the resistances by different forms of carriages, Mr. GEORGE STEPHENSON and myself, in October, 1818, commenced a series of experiments upon the Killingsworth Rail-road, to ascertain that desideratum.

A spring dynamometer was first used, but we found its action subject to such irregularity, that we were obliged to abandon it, and resort to one of the following construction:—

A very heavy pendulum, or leaden weight A, *Fig.* VI. *Plate* IV. was suspended by the arm *b* from a well-turned

and perfectly smooth axle, *c*, moving freely upon a brass carriage or chair, which was kept well oiled, and moved with very little friction. A grooved quadrant, *d e*, accurately formed, was fixed at the extremity of the pendulum, and moved with it, as shewn in the drawing. Upon the side of the periphery of the quadrant a graduated index was made, on which were marked divisions representing pounds. A pointer was screwed to the frame of the carriage at *e*, in such a manner as to be capable of being adjusted to suit the angle of the road, so that when the pendulum was perpendicular, the pointer should indicate 0.

It will be readily seen from an inspection of the drawing, that when the pendulum was left at liberty, it would assume a position perpendicular to the horizon, or hang freely down; and that it would require a certain force to remove it from that position, which force would vary according to the different angles it was made to form with respect to the horizon. The dotted line *e g* will represent the arc of the circle which the pendulum would describe, and the greatest force which it would present to any power, drawing it out from the position it would assume, would be when it arrived at *g*, or became parallel with the horizon.

Knowing the weight of the leaden ball, and the length of the arm of the pendulum, it would have been easy to calculate the scale of divisions representing pounds; but, we preferred marking them by employing known

weights to drag the pendulum out from the perpendicular. To accomplish this, we used a steel-yard, made for the purpose, with arms of equal lengths at right angles, or forming an angle of 120 degrees with each other, one of which would thus be perpendicular, and the other horizontal; this rested on a pivot, with sharp points, balancing each other with great nicety; from the horizontal arm known weights were suspended, and from the end of the perpendicular arm a rope proceeded, which passed round the groove of the quadrant, and was fastened at *d*. The weights were added pound by pound, and the steel-yard adjusted at each operation; and, as the weights drew the pendulum out from the perpendicular, the divisions were marked on the index. The same rope was used in the experiments, that was made use of to adjust the instrument.

This instrument, which is a perfect dynamometer, was firmly fixed to the carriage C D, by the frame *ffff*, placed upon wheels of such a height that the rope, leading away in a tangent horizontally from the quadrant, could be fastened to that part of the carriages by which they are usually drawn along upon the Rail-road.

The carriage containing the dynamometer was placed upon the Rail-road, and the rope

fastened to the carriage, the friction of which was the subject of experiment, in the same manner as represented in the drawing. Manual labour was then applied to the dynamometer-carriage to push it along the Rail-road, and the rope being fastened to the waggon, it was also drawn forward. The distance which the pendulum was drawn out from the perpendicular, by the action of the rope, was, therefore, the measure of force or pressure required to move the waggon forward upon the Rail-road.

Before recording the pressure, indicated by the index, both carriages were put into a certain velocity, and that velocity was kept up as equable as possible during the course of the experiment. At first it was found rather difficult to preserve a state of perfect uniform velocity, the least variation in the force applied to push the dynamometer forward, causing the index to vibrate backwards and forwards; by employing a greater number of men, we accomplished, after successive trials, a regularity of action, which produced the most uniform velocity in the motion, and each experiment was repeated until we were perfectly satisfied of the accuracy of the result.

The degree of force, indicated by the dynamometer, was, therefore, that which was

required to keep the waggon in motion, or to keep it in a state of uniform velocity, that velocity being first produced by other means. Before, however, proceeding further, it may be necessary to define what is meant by friction, and explain the laws which regulate its action upon bodies moving upon Rail-roads.— As previously stated, when two surfaces are in contact, and subjected to a determinate pressure, it requires a certain force to cause them to slide over each other; and this property of resisting sliding, was called the adhesion of the surfaces. Friction, then, is meant as a measure of this resistance, or the amount of friction is the force required to cause the bodies to slide over each other.

It is a well-known law of dynamics, that every body has a tendency to continue either in a state of rest, or of uniform rectilinear motion, unless disturbed by some extraneous mechanical force. Let, therefore, a carriage be placed upon a Rail-road, and a certain velocity be given to it, by any force or pressure whatever — if we suppose the body and plane perfectly void of friction, and free from the action of any other force, then the body will continue to move on uniformly with the velocity given to it, until disturbed by some accidental force or cause; for the body has no

power in itself to change that velocity, and it is not supposed to be effected by any other mechanical force whatever.—Suppose, now, instead of the body being perfectly free from friction, that it is continually opposed by a certain determinate force or pressure, which is always acting with the same intensity, in retarding the progressive motion of the body; then the body, instead of continuing in a state of uniform motion, will, by the constant retardation of this force, be soon brought to a state of rest. Suppose, however, when it is in a state of uniform velocity, and subjected to the action of this retarding force, we apply, or cause a force continually to act upon the body, urging it forward with the same intensity of pressure that the retarding force, or friction of the body, opposes to its progressive motion—then the body will still continue to move on in a state of uniform velocity, and with the same velocity given to it. When, therefore, a carriage is placed upon a Rail-road, and a continual pressure is exerted upon it, to urge it forward, (as the action of the men through the medium of the rope of the dynamometer;) it is found that, with whatever velocity it is moved, supposing the moving force to proceed with the same velocity, the pressure required to keep it in a state of uniform

motion is the same at any velocity. Hence, the friction is said to be a constant *or uniform retarding force of the same intensity, whatever be the velocity with which the body is moved,* — and that the force or intensity of pressure required to act upon the body, to move it over any determinate space at different velocities, will be the same at each instant of time; consequently, the aggregate amount of power required to drag any body over a given space, will always be the same, whatever be the velocity; but, if we traverse that space in half the time, it will of course require the moving power to travel at twice the velocity; and, therefore, the aggregate effort of mechanical power required will be double, acting half the time; and, at different velocities, will be represented by the following diagram.

I.

Velocities - -	1	2	3	4
Spaces passed over -	1	1	1	1
Times - - - -	1	1	1	1
Resistance - - -	1	1	1	1
Mechanical force required, acting in the above time	1	2	3	4
Mechanical force required, for any given distance	1	1	1	1

If experiment proves that the intensity of force required to urge the body forward is

not the same at all velocities, then the friction is not an uniform retarding force, *but increases in the ratio of the velocity;* for instance, when the body is moved forward at twice the velocity, if the pressure indicated by the dynamometer be twice as great as when moving at half the velocity, then the aggregate amount of force required to move the body over a given space with twice the velocity, will be twice that required to move the body over the same space, with half that velocity; and, consequently, by traversing that space in half the time, the moving power will also travel at twice the velocity; and, therefore, the mechanical power required will be four times the amount, acting half the time; and the undermentioned diagram will shew the mechanical force required at different velocities—

II.

Velocities - -	1	2	3	4
Spaces - -	1	1	1	1
Times - - -	1	1	1	1
Resistance - -	1	2	3	4
Mechanical force required, acting for the above time	1	4	9	16
Mechanical force required, for any given distance	1	2	3	4

Again, if the resistance *increases in the ratio of the square of the velocity,* then the amount of

mechanical force required to move the body forward, at different velocities, will be as follows :—

III.

Velocities - -	1	2	3	4
Spaces - - -	1	1	1	1
Times - - -	1	1	1	1
Resistance - -	1	4	9	16
Mechanical force required, acting for the above time	1	8	27	64
Mechanical force required, for any given distance	1	4	9	16

I would not have been thus particular in my elucidation of the effects of friction, had I not found that considerable ambiguity existed on the amount of resistance at different velocities. —I trust the foregoing explanation, if it do not dispel the ambiguity, will at least make the reader acquainted with the sense in which I shall hereafter use it in the work.

Experiments made at Killingsworth Colliery, with the dynamometer, to ascertain the friction or resistance of carriages moved along Rail-roads.

The rails were of cast-iron. Edge-rails of Messrs. Losh and Stephenson's plan, *Fig.* I.

Plate II. Flat bearing surface $2\frac{1}{2}$ inches broad, 3 feet $9\frac{1}{2}$ inches long; the plane, a piece of road selected for the purpose, was quite straight, and with a uniform inclination of .0738 inches in a yard, or one yard in 488. The carriages were the same as used upon the road for the conveyance of Coals, and similar to that shown in *Fig*. VII. *Plate* IV. The wheels were fixed upon the axles, and turned with them; their diameter was 34 inches, with a projecting ledge of three-quarters of an inch, to keep them upon the road.—The body of the carriage rested by a chain of brass or iron, upon the axles of the wheels, as explained in the detail of the experiments; the axles being of wrought-iron, $2\frac{1}{4}$ inches diameter at the bearing.

EXPERIMENT II.

	DESCRIPTION OF CARRIAGES.	Resistance up the plane.	Resistance down the plane.	Mean resistance, or friction upon a level plane.
		lb.	*lb.*	*lb.*
1	Loaded carriage, weighing 23¼ cwt., and containing 53 cwt. of Coals. Total weight 76¼ cwt. Wheels cast-iron, case-hardened, and had been in use six months. The bearings upon the axles of cast-iron, four inches broad - - - -	56	22	39
2	Loaded carriage, same weight as the preceding, wheels cast-iron, but not case-hardened, and were worn considerably. Chairs or bearings brass, 1¼ inches broad - - - -	78	48	63
3	Four empty carriages, each weighing 23¼ cwt. Three with case-hardened wheels, and one with wheels not case-hardened, same kind of bearings as No. 1. - - - - -	74	32	53
4	Four empty carriages, same weight as the preceding, three with common, and one with case-hardened wheels, bearings brass, similar to No. 2. - - - -	91	49	70
5	Four empty carriages, same weight as No. 3., all with old wheels, not case-hardened, much worn or indented on the rim, wrought-iron bearings, 1¼ inches broad - - -	112	70	91
6	The preceding twelve empty carriages together - - - - - -	277	149	213
	After the above experiments were performed, there appeared such a variation in the result between the carriages, having different kinds of wheels and bearings, the following were made to ascertain how much the resistance was affected by each. - - - -			
7	Four empty carriages, and weighing 23¼ cwt., all with case-hardened wheels, and cast-iron bearings, similar to No. 1. - - -	72	29	50
8	Four empty carriages, same weight, with case-hardened wheels and brass bearings, same as No. 2. - - - - -	75	33	54
9	Four empty carriages, same weight, wheels not case-hardened, half wore, bearings similar to No. 7. - - - -	90	48	69
10	Four empty carriages, same weight, wheels same as preceding, or No. 9, brass bearings, similar to No. 8. - - - -	96	54	75
11	Four empty carriages, same weight, case-hardened wheels, wrought-iron bearings, same as No. 5. - - - -	89	47	68

A very material difference in the result will be found in these experiments, in the construction of the carriages. The carriage, No. 1, was of the most modern construction, and the resistance upon a level plane amounted to no more than 39 lbs. The carriage, No. 2, required 63 lbs. almost two-thirds more; but, as the bearings and wheels were different, it was desirable to find to which the variation was attributable.

On comparing No. 8 and No. 10 together, which had the same kind of bearings, but different wheels, it will be seen, that in the four empty carriages there is a difference in the resistance of 21 lbs., which must arise from the wheels alone. The whole weight of those carriages were 93 cwt.; therefore, the additional resistance, occasioned by wheels partly worn or indented into a groove around the rim of the wheel, amounts to nearly the 500th part of the weight. Again, on comparing No. 7 and No. 8, we find the difference nearly the same, amounting to the 550th part of the weight. This proves the great superiority of case-hardened wheels over the common ones, not only in economy, but also in lessening the resistance. It has been urged against them, that their hardness makes them liable to cut the rails; this might apply to narrow rubbing

surfaces, but cannot have any connection with one surface rolling over another, especially when the hard surface is the rolling one, and also the broader. I have often examined, very carefully, their action upon the rails, but could never find any tendency in them to cut the rails; when the common wheels are indented on the surface of the rim, they are very liable to injure the rails, from their grooved periphery breaking the sides of the bearing surface of the rail off, and leaving only the middle section.—This is very frequently the case, as may be seen on all those Rail-roads upon which the common wheels have been used. The universal adoption of case-hardened wheels, on all the principal Rail-roads, in preference to the common wheels, is however the best criterion which can be adduced, of the general belief of their superiority. The case-hardening of the wheels is, as previously explained, effected by running the metal against a cold cylinder of cast-iron. I am inclined to think this also tends to form the wheel more perfectly cylindrical than casting in the ordinary way, which will also lessen the resistance, and remedy any resistance produced by the undulatory motion, from the imperfect circular form of the rim.

In examining these experiments, there is

also another variation in the result, owing to the different kinds of bearings employed. Comparing the resistance of No. 8 with No. 7, there appears a difference of four pounds, which is equal to one pound in each carriage, between bearings of cast-iron and of brass, the iron bearings are broader than those of the brass, and this will, perhaps, account for the difference; otherwise the brass would most likely have been found to present the least friction; but it at the same time proves the necessity of making the bearings of a certain size, compared with the pressure upon them, and shows that the brass is considerably below that size; inasmuch, as we find that the increased breadth of the cast-iron more than compensates for its inferiority to brass, in diminishing the friction.

We had also an opportunity of subjecting to the test of experiment, another kind of bearing, which, for a long period after the introduction of Rail-ways, was universally used, and I believe is still used in many places.—This is a malleable iron bearing, formed by the hammer of the blacksmith, one inch and a quarter broad; this was the bearing used in No. 11, which, on being compared with Nos. 7 and 8, a difference will be found amounting to 19 lbs. between that kind of bearing and the

cast-iron, and 15lbs. between it and the brass, which is equal to the difference between the common and the case-hardened wheels, and amounting to nearly the 550th part of the weight. This is not the only evil produced by the use of this kind of bearing; it also operates very powerfully in cutting the axles. On being shewn two axles, it is readily distinguishable to which kind of bearing each had been subjected; the axle with the narrow bearing is cut and furrowed, while the other is smooth and even; and it need not be stated, the effect which such a cause would produce in the expence, by the destruction of axles.

The reduction of friction, by these two causes, are very considerable, and, when properly estimated, are of great moment in the economy of Rail-road conveyance. The two together amounts to the 275th part of the weight of the carriage, and equal to 43 per cent. of the whole amount of friction.

The following are some experiments which I made upon the Hetton Colliery Rail-road, in December, 1824, which ascertaining the friction by other methods, will be interesting as a comparison with the preceding. Length of plane 1164 feet, perfectly straight, with an uniform and regular descent of one yard in 104.24 or 11 feet 2 inches in the whole distance.

Edge-rail of LOSH and STEPHENSON'S patent, $2\frac{1}{2}$ inches broad at top. The carriages were allowed to descend freely by their gravitating force, and the space they passed over ascertained by a stop-watch.

EXPERIMENT V.

Four loaded carriages, each weighing 9408 lbs. with case-hardened wheels, two feet eleven inches diameter, malleable iron axles, three inches diameter, bearings cast iron, four inches broad.

Space described 1164 feet—time 120 seconds.

By theorem B. $F = G \frac{WS}{rt^2} =$ 216 lbs. the friction of the four carriages, and $\frac{216}{5} =$ 43 lbs. the friction of each carriage.

EXPERIMENT VI.

Seven loaded carriages, similar to the above, described precisely the same space, in the same time, making their friction the same as the above, viz. 43 lbs.

During the time of performing these two experiments, it was a dead calm, not the least wind; and the rails were dry, and in that state which would present almost the least resistance to the wheels.

EXPERIMENT VII.

Same plane, with one loaded carriage, similar to the preceding, space described 1266 feet, time of descent 128 seconds.

By Theorem B. as before

$$F = G \frac{WS}{rt^2} = 45 \text{ lb. the friction.}$$

EXPERIMENT VIII.

Same plane, same kind of carriage.

One loaded carriage. Space describes 1140 feet. Time 125 seconds.

By Theorem B. Friction equal 47 lbs.

EXPERIMENT IX.

Same plane, an empty carriage, similar in form to the preceding, weighing 3472 lbs. space described 1206 feet. Time 124 seconds.

By theorem B. Friction 16.25 lbs.

During the time of performing the three last experiments, it was rather windy, and the direction of the wind was partly obliquc to the line of the road, which would have the effect of blowing the carriage rather to one side, and causing the projecting ledge of the wheels to press or rub against the side of the rail, and thus consequently augment the friction. The increase of resistance, or retardation, caused by the wind is sometimes very considerable, especially when the direction is oblique to the line of the road, as then the wind not only acts by its direct impulse upon the carriages, but also in forcing the wheels against the side of the rail, and increasing the friction by the projecting ledge rubbing against the rail. In the last three experiments the rails were in an excellent state, presenting the least possible resistance to the rolling of the wheels. When the rails are quite dry, or quite wet, they

present the least, and when partially wet or moist, and catching the dust, the resistance is the greatest; in these three last experiments they were quite dry.

By comparing the friction of the empty with the loaded carriages, we might have found if the friction increased in direct, or in any other proportion with the weight; as, however, the carriages experimented upon were not all the same, though of the same construction, it was necessary to try the friction directly, by loading the same carriage with different weights, and the following experiments were made for that purpose with the dynamometer.

EXPERIMENT X.

Number of Experiments	DESCRIPTION OF CARRIAGES.	Resistance up the plane
1	Carriage with common wheels, and cast-iron chairs, four inches broad, wheels thirty-four inches diameter, axles 2¾ inches diameter, weight of the body of the carriage resting upon the axle, 12cwt. and weight of the wheels and axle 11cwt. loaded with 20 cwt. of iron, upon the same plan as experiment II. - - - -	36
2	Same carriage, loaded with 40 cwt. of iron -	48
3	Ditto loaded with 53 cwt. of iron -	58
	Immediately after the above experiments were finished, a smart shower of rain fell, attended with a brisk squall of wind, during which we availed ourselves of the opportunity of ascertaining the variation in the resistance by the rails being partly wet.	
4	Same carriage, loaded with 53 cwt. of iron -	65
5	Ditto. Ditto. 40 cwt. of iron - -	52
6	Ditto. Ditto. 20 cwt. of iron - -	38

On examining the result of the foregoing experiments, we find the friction is not precisely proportionate to the weight, but nearly so. The friction of the rubbing upon the axle, and the resistance of the wheels upon the rail, does not appear to follow the same law. It would have been highly desirable if they could have been subjected separately to the test of experiment, that we might be able to deduce from the known amount of friction of the one, the friction of the other; but, in the absence of such experiments, we must content ourselves with as near an approximation as the extent of our information reaches. Assuming the friction to be as the weight, and taking No. I. as a standard, we should have for the other, when the whole weight of carriage and wheels is taken into account, 53 and 64 lbs. respectively, whereas, experiment gives 48 and 58 lbs. which shows that the friction does not increase in so great a ratio as the weight. This, no doubt, arises from a part of the whole weight being subjected to the action of rolling only, (viz. the weight of the wheels and axles,) the resistance from which cannot amount to so much as a like weight, subjected to the action of attrition upon the axle, and also of the rolling of the wheel upon the rail, as takes place with the body of the carriage resting upon the axles.

But, in this experiment, the rails were completely free from dust, were quite dry, and would consequently present little resistance to the wheels rolling upon them; during a shower of rain, when the rails were partly covered with mud, and the resistance became greater, we find it to correspond very nearly with the simple ratio of the weight.

In practice, therefore, we may I think safely take the friction to be as the weight of the carriages.

The following Table will shew the result of the foregoing Experiments on the friction of carriages moving along the Edge Rail-road.

TABLE I.

Number of Experiment.	Reference.	Weight of the carriages in lbs. including wheels and axles.	Amount of friction in lbs.	Ratio of friction to weight, friction being 1.	Ratio of diameter of wheels to diameter of axles, or of rolling to rubbing surface; diameter of axles being 1.	Ratio of friction of rubbing surface to weight, rubbing surface 1.
1	By dynamometer, Exp. IV. *No.* 1.	8540	39.	219.	12.36	17.7
2	Ditto Exp. X. *No.* 3.	8512	40.	212.8	12.36	17.2
3	Ditto ditto *No.* 2.	7056	34.	207.5	12.36	16.8
4	Ditto ditto *No.* 1.	4816	24.	200.6	12.36	16.2
5	Ditto ditto *No.* 4.	8512	45.	189.	12.36	15.3
6	Ditto ditto *No.* 5.	7056	38.	185.6	12.36	15.
7	Ditto ditto *No.* 6.	4816	27.	178.3	12.36	14.4
8	Inclined plane, Exp. V.	9408	43.	218.7	11. 6	18.8
9	Ditto Exp. VI.	9408	43.	218.7	11. 6	18.8
10	Ditto Exp. VII.	9408	45.	209.	11. 6	18.
11	Ditto Exp. VIII.	9408	47.	200.	11. 6	17.2
12	Ditto Exp. IX.	3472	16.25	213.6	11. 6	18 4
13	Dynamometer, Exp. IV. *No.* 7.	2604	13.	200.3	12.36	16.1

By the above table it will be seen that the least amount of resistance is equal to the two hundred and nineteenth part of the weight of the carriage, and the greatest equal to the one hundred and seventy-second part, and that the average of the whole will be about the two hundredth part of the weight. Expressing the friction in terms of the weight, without reference to the size of the wheel, is not, however, the most correct way of conveying an idea of its effects; as, by placing the weight upon larger wheels, we diminish the quantity of rubbing surface, and of course the friction, while the weight remains the same. The most correct expression would, perhaps, be in comparison with the extent of rubbing surface, as that alone varies with the size of the wheels. Column the sixth shews the ratio of the diameter of the wheels to the diameter of the axle, which also expresses the velocity or extent of rolling, compared with the rubbing surface exposed to friction, the latter being denoted by 1. The difference between these two will, therefore, represent the diminution in the amount of friction produced by the employment of the great circumference of the wheels to effect the progressive motion of the carriage, and the less circumference of the axle to support its weight; and by as much as the one

exceeds the other, by so much is the quantity of rubbing surface diminished, and consequently the friction arising from that cause.

Column 7th expresses the proportion which the friction bears to the weight, compared with the extent of rubbing surface upon the axles. Thus, in No. 1, the friction is equal to the two hundred and nineteenth part of the carriage, and this friction is caused by the action of the wheels rolling upon the rails, and the weight rubbing upon the axles; but the proportion which the action of the former bears to the latter, is as 12.36 : 1; we diminish then in that proportion the friction; or at least that which arises from the attrition upon the axle, and which, upon an edge rail-way, constitutes a greater part of the resistance; and, by using different-sized wheels, we diminish the resistance from that cause, in direct proportion to the difference between the diameter of the wheels and that of the axle.

Column 7 will then express the friction compared with the extent of rubbing surface. To find the friction of carriages placed upon any size of wheels, we have only to multiply this sum by the diameter of the wheels and divide by the diameter of the axle, and the dividend will give the friction or resistance of the carriage upon an edge rail-road.

Having thus ascertained the friction relative to the weight, the following experiments were made with the dynamometer, to ascertain the friction or resistance of carriages moving at different velocities.

EXPERIMENT XI.

No	DESCRIPTION OF CARRIAGES, AND VELOCITIES AT WHICH THEY MOVED.	Resistance in lbs.
1	Loaded carriage, weighing 22½ cwt. with cast-iron bearings, four inches broad, case-hardened wheels thirty-four inches diameter, and wrought-iron axles two and three quarter inches diameter, containing 53 cwt. of coals, moved at a slow rate of motion - -	56
2	Moved at the rate of 134 feet in a minute - -	56
3	Ditto 307 Ditto - -	56
4	Ditto 397 Ditto - -	56
5	Ditto 140 Ditto - -	56

In prosecuting the above experiments, the carriage and dynamometer were first put into the required velocity, and that velocity was uniformly kept up during their passage along the plane. Numerous trials were made, to be certain that the result was correct; the dynamometer was pushed along by several men, and the variation from a uniform resistance, indicated by the index, was so trifling, that no other record than those in the table could be made. This experiment was made, in conjunction with Mr. Stephenson, in 1819.

To determine this question by a method different from the preceding, and where, perhaps,

the liability to error was less, I lately made the following experiments upon a certain stage, or piece of Rail-road, selected for the purpose. A perfectly straight plane of the Edge Rail-road, with a uniform and regular inclination, was taken, the declivity of which was such as would cause the carriages to descend with an accelerated velocity; a carriage was placed upon it, and allowed to descend freely, and the space it passed over in successive portions of time, was marked with the utmost accuracy in the following manner—standing upon one end of the carriage, and aided by an assistant, at the end of every ten seconds I made a mark upon the plane where the carriage happened to be, and afterwards measured the distance between those marks, which gave the space passed over in each successive period. The carriage was first put in motion at the top of the plane, by a slight impulse, only sufficient to overcome its *vis inertia*. The descent of the plane was 1 yard in 200 yards, or 134 inches, in 13968 inches,

EXPERIMENT XII.

No. 1.			No. 2.			No. 3.		
Loaded carriage, weighing 9,408 lbs., wheels 35 inches, axles 3 inches diameter.			Loaded carriage, weighing 9,408 lbs., wheels 35 inches, axles 3 inches diameter.			Empty carriage, weighing 3,472 lbs., wheels 35 inches, axles 3 inches diameter.		
Time of descent.	Space passed over.	Calculated space by formula A $S=\frac{G-F}{W}\times rt^2$	Time of descent.	Space passed over.	Calculated space by formula A $S=\frac{G-F}{W}\times rt^2$	Time of descent.	Space passed over.	Calculated space by formula A $S=\frac{G-F}{W}\times rt^2$
Sec.	Feet.	Feet.	Sec.	Feet.	Feet.	Sec.	Feet.	Feet.
18	25	26	5	2.8	1.9	14	15.1	16.5
28	71.9	63	15	20.4	18.	24	89.	46.2
38	124.6	116	25	54.7	50.2	34	147.8	92.9
48	205.2	185	35	97.	98.6	44	221.	155.6
58	276.5	270	45	158.3	162.8	54	304.2	234.5
68	384.7	371.8	55	234.2	243.2	64	425.	329.3
78	506.1	489.2	65	314.7	339.7	74	487.6	448.3
88	645.5	622.6	75	442.1	452.3	84	595.2	567.8
98	785.3	722.2	85	501.5	581.	94	733.8	677.2
108	939.6	937.9	95	642.1	642.1	104	891.5	869.7
118	1081.6	1119.6	105	800.5	886.5	114	1048.6	1045.
128	1266.5	1318.3	115	965.5	1063.5	124	1205.7	1236.4
			125	1140.4	1256.5			

It will be seen, from the preceding experiments, that the actual space passed over is greater, until a certain period of the time, than the calculated space; which arose from the wind blowing pretty strong in the same direction of the line of the plane, as that in which the carriage was descending, which had the effect of urging it forward, until its velocity became equal to that of the wind. In trying the experiment, the pressure of the wind was felt while descending with the carriage, until a certain period, when it appeared quite calm; and this took place somewhere about the end of the 110th or 120th second, where we find the calculated

space agree with that actually passed over. This might be expected, as the calculated space is derived from the descent of the same carriage during a calm, *(see Experiment V.)* where the space passed over was nearly the same, and, consequently, the effect of the air, in retarding the velocity of the one, would be equal to the effect of the wind in accelerating the other, when the velocities became equal, and that velocity corresponded with the velocity of the wind.

Not having an opportunity of making the experiment upon this piece of road during a calm, I selected a short distance of the Killingworth Rail-way, with a nearly uniform descent, and embraced an opportunity of trying the experiment, when there was scarcely any wind, or at least so little that it could have no sensible effect, either in retarding or accelerating the velocity of the carriage. The descent of plane was not uniformly the same throughout the whole length, but, to ascertain the true result, I took the actual descent at the end of the several spaces passed over.

The following table will show the result:—

EXPERIMENT XIII.

Loaded Carriage weighing 9,100lbs., wheels 34 inches, axles 2¼ inches.				
Time of descent.	Space actually passed over.	Descent of plane.	Calculated space on a plane with uniform descent.	Descent of plane if the inclination had been uniform.
Seconds	Feet.	Inches.	Feet.	Inches.
10	6.	1.	6.6	0.7
20	26.4	3.5	26.4	2.94
30	59.8	7.5	59.4	6.72
40	106.2	12.	105.6	11.8
50	165.	19.	165.	18.3
60	242.8	26.	237.6	26.9
70	326.7	37.	321.4	36.3
80	424.3	46.	422.4	47.1
90	525.3	57.	534.6	58.4
100	635.5	70.	660.	70.6

The preceding experiments show that the friction is not greater when the velocity is increased, more than what arises from the retardation caused by the air.

In practice we may, therefore, take the friction of carriages moved along Rail-roads, as a uniform and constant retarding force. And the resistance respectively opposed to the moving power, at different velocities, as represented by the Diagram (I) page 181.

The following experiments were made to ascertain the resistance of carriages moved along the plate-rail, with the same dynamometer used in the previous experiments, and shewn in *Fig.* VI. *plate* IV.

The rails were each 4 feet long and $3\frac{5}{8}$ inches broad where the wheel runs upon them; and the height of the upright ledge three inches.

Number of experiments.	DESCRIPTION OF CARRIAGES.	Resistance up the plane.	Resistance down the plane.	Mean resistance.
1	Two loaded carriages, each weighing 8,512 lbs.; cast-iron wheels, $39\frac{1}{4}$ inches diameter, $1\frac{3}{4}$ inch broad, upon the rim which runs upon the rails; brass-bearings $1\frac{3}{4}$ inch broad, diameter of axle $2\frac{3}{4}$ inches	168	126	147
2	Six empty carriages, each weighing 2,576 lbs.; construction same as preceding - - - - -	187	147	167

From these experiments, we find the resistance of a loaded carriage weighing 8512lbs. to be 73.5lbs. which is equal to the 116th part of the weight; and, comparing this with No. 2, Experiment IV. which had the same kind of bearing, *we find the relative resistances of the plate to the edge-rail as* 73 : 63, which gives the most decided preference to the latter.

CHAPTER VII.

EXPERIMENTS MADE ON THE FRICTION OF ROPES ON INCLINED-PLANES.

Ropes being most generally used, as a medium of communication between the moving

power and the resistance, in dragging carriages up acclivities, along level planes, or for lowering them from one level to another upon Rail-roads; it is not only interesting, but, in the case of the self-acting planes, absolutely necessary, that a proper estimate of their friction should be obtained.

In fixed-engines, where loads are dragged forward upon carriages by means of ropes, unless we can calculate, *à priori*, the friction or resistance opposed by the use of such rope, we are at loss to know how much engine-power is required to overcome the resistance to obtain the requisite velocity, and we may, by overrating its effects, load the engine with unnecessary strength and power; or, by under-rating, erect an engine not adequate to perform the desired effect.

In self-acting planes, where gravity is the moving power, it scarcely need be stated, that the strictest regard should be observed in economising its effects; the power itself is acquired at no cost; and, on that account, its action should be extended to the utmost limit of its applicability.

The following experiments are selected, from a great many which I have been allowed to make upon the different Rail-roads in the neighbourhood of Newcastle-upon-Tyne, and are such as appeared to me to be sufficient to shew the requisite resistance, and

from which may be deduced the necessary data for calculating the effects upon other planes.

EXPERIMENT XIV.

Upon the Killingworth Rail-road; self-acting plane with a single sheeve, round which the rope winds, one end of which is attached to the descending, and the other to the ascending carriages; length of the plane 715 yards, descent 57 feet 6 inches. Five loaded carriages, each weighing 8764 lbs., descended by their gravitating force, and drew up 6 empty carriages, each weighing 2800 lbs. on a mean of several times, in 200 seconds; wheels 34 inches diameter, axles $2\frac{3}{4}$ inches diameter, size of rope 5 inches circumference, weight 3884 lbs. The descent of this plane is not regular, being greater at the top than at the bottom, the rails being laid, as shewn in *Fig.* I. *Plate* V., the line of road perfectly straight. Number of sheeves in action at once 73, weight 3297 lbs., diameter of sheeve where rope runs, 11 inches, and diameter of the axles $\frac{3}{4}$ of an inch, ratio 14.65 : 1; weight of wheel W W 4636 lbs., diameter 10 feet, and diameter of axle 6 inches, ratio 20 : 1.

The gravity of the loaded carriages will be

$$G = \frac{W\,H}{L} = \frac{8764 \times 5 \times 57.5}{2145} = 1175 \text{ lbs.}$$

and the gravity of the empty carriages will be

$$g = \frac{wH}{L} = \frac{\overline{2800 \times 6 \times 57.5}}{2145} = 450 \text{ lbs.}$$

Taking the friction of the carriages, which were similar to those used in Experiment IV. at $F = 40$ lbs. and $f = 14$ lbs. respectively, we have by theorem D

$$F' = G - \frac{(W + w) \times s}{rt^2} = 1175 - \frac{43820 + 16800) \times 2145}{16\tfrac{1}{12} \times 200^2}$$

$= 973$ lbs. whence by theorem $F = F' - (F + f + g) = 973 - (200 + 84 + 450) = 239$ lbs. the friction or resistance of the rope.

EXPERIMENT XV.

Same plane, and similar carriages; 6 loaded carriages drew up the plane 7 empty carriages in 180 seconds.

Theorem $G = \frac{\overline{8764 \times 6 \times 57.5}}{2145} = 1410$ lbs.

and $g = \frac{\overline{2800 \times 7 \times 57.5}}{2145} = 525$ lbs.

also $F' = 1410 - \frac{\overline{52584 + 19600} \times 2145}{16\tfrac{1}{12} \times 180^2} = 1113$ lbs.

and $\phi = 1113 - \overline{525 + 240 + 98} = 250$ lbs. the friction of the rope.

The above plane, in practice, requires always six loaded carriages descending, to drag up six empty carriages. In fine weather, and when the rails are in good order, the brake or convoy is not required; but, in windy weather, or when the rails are not in a good state, the six loaded carriages have some diffi-

culty in overcoming the resistance of the 6 empty carriages and rope. With 6 carriages, therefore, this plane may be taken as an instance of the least inclination that can be used in practice, to secure a regular and constant conveyance in all states of the weather. When at regular work, the usual time of descent is from 3 to 4 minutes.

Taking the above number of loaded carriages as necessary to effect the constant passage of the empty carriages up the plane,

We have the gravitating force, or moving power, $G = 1410$ lbs., and the friction or resistance of the whole train being $F' = 1010$ lbs. leaving a surplus of gravitating force equal to 410 lbs. to effect the motion of the whole matter upon the plane with the requisite velocity in all states of the weather.

EXPERIMENT XVI.

Self-acting plane, with wheel, similar to *Fig.* I. *Plate* III., 6 feet diameter. Length of plane 3906 feet, height 130 feet 4 inches. The descent of this plane is not regular, and has a considerable curve also in the line of road. Weight of inclined-wheel 454 lbs., diameter 6 feet, diameter of axle 3 inches; number of rollers in action at once 144, weight 4448 lbs.; circumference of rope 5 inches, weight 4807 lbs.; ratio of diameter of sheeves to diameter of axle 14 : 1

Five loaded carriages, same as Experiments V. and VI., each weighing 9408 lbs., descending drew up 7 empty carriages, similar to Experiment IX., each weighing 3472 lbs., in 300 seconds.

$$\text{Theorem } G = \frac{\overline{9408 \times 5} \times 1564}{46872} = 1570 \text{ lbs.}$$

$$g = \frac{\overline{3472 \times 7} \times 1564}{46872} = 811 \text{ lbs.}$$

$$F' = 1570 - \frac{\overline{47040 + 24304} \times 3906}{16\frac{1}{12} \times 300^2} = 1378 \text{ lbs.}$$

and $\phi = 1378 - \overline{811 + 215 + 112} = 240$ lbs. friction or resistance of the rope.

This plane, when at regular work, is always employed with seven loaded and seven empty carriages, which effect a constant action during all states of the weather, and have also a surplus of power, as the brake or convoy is always used upon particular parts of the plane.

With the above number in action we have $G = 2198$ lbs. and $F' = 1455$ lbs., which is much greater than necessary to effect the requisite velocity.

EXPERIMENT XVII.

Self-acting plane-wheel, same as preceding, 6 feet in diameter, weight 454 lbs., ratio of diameter to diameter of axle 24 : 1, length of plane 3672 feet, height 129 feet 6 inches,

descent not uniform, with a curve in the middle, forming part of a circular arc. Number of sheeves 263, weight 9759 lbs., ratio of diameter of sheeves to diameter of axle 14 : 1; rope 1200 yards, weight 4468 lbs., circumference 5 inches.

Five loaded carriages, similar to the last experiment, each weighing 9408 lbs., descended against 7 empty carriages, each 3472 lbs., in 360 seconds.

$$\text{Theorem } G = \frac{\overline{9408 \times 5} \times 1554}{44064} = 1659 \text{ lbs.}$$

$$g = \frac{\overline{3472 \times 7} \times 1554}{44064} = 857 \text{ lbs.}$$

$$F' = 1659 - \frac{\overline{47040 + 24304} \times 3672}{16\frac{1}{12} \times 360^2} = 1534 \text{ lbs.}$$

and $\phi = 1534 - \overline{857 + 215 + 112} = 350$ lbs. the resistance of the rope.

The same number of carriages are usually employed on this plane as on the preceding, which leaves a considerable surplus of gravity to effect their motion upon the plane.

EXPERIMENT XVIII.

Self-acting plane, similar to the two last; length 2706 feet, height 76 feet 5 inches, descent nearly uniform, and line of direction quite straight; weight of wheel 454 lbs., ratio of wheel and axle 24 : 1, number of sheeves

139, weight 4173lbs., ratio of diameter 16 : 1, rope 1000 yards, $4\frac{1}{2}$ inches circumference, weight 2927 lbs., inclined-wheel same as above.

Five loaded carriages descended the plane, and brought up 7 empty carriages, same weight as preceding, in 280 seconds.

$$\text{Theorem } G = \frac{\overline{9408 \times 5} \times 917}{32472} = 1328 \text{ lbs.}$$

$$g = \frac{\overline{3472 \times 7} \times 917}{32472} = 686 \text{ lbs.}$$

$$F' = 1328 - \frac{\overline{47040 + 24304} \times 2700}{16\tfrac{1}{12} \times 280^2} = 1175 \text{ lbs.}$$

and $\phi = 1175 - \overline{686 + 215 + 112} = 162$ lbs. the friction of the rope.

The number of carriages, used in practice upon this plane, are 7 descending against 7 ascending; but there is always more than sufficient preponderance.

EXPERIMENT XIX.

Fixed-engine plane, where a steam-engine of 60-horse power is erected, to drag the loaded carriages up; length 2646 feet, height 154 feet 6 inches, descent not regular, being less near the top than at the bottom; line curved laterally in the middle, forming an arc, the versed sine of which is about 40 yards. Rope-roll similar to A, *Fig.* II. *Plate* III., on which the engine winds the rope, and which, during the experi-

ment; was thrown out of gear, as shewn in the drawing, the descending carriages unwinding the rope; weight of rope-roll with cog-wheels 8960 lbs., ratio of diameter to diameter of axle 10:1, number of sheeves 161, weight 10,278 lbs., ratio of diameter to diameter of axle 14:1; length of rope 1000 yards, $7\frac{1}{4}$ inches circumference; weight 6967 lbs.

Three empty carriages, each weighing 3472 lbs., descended and dragged the rope out from the engine in 174 seconds.

$$\text{Theorem } G = (3472 \times 3) \times \frac{1854}{31752} = 608 \text{ lbs.}$$

$$\text{and} \qquad F' = 608 - \frac{10416 \times 2646}{16\frac{1}{12} \times 174^2} = 552 \text{ lbs.}$$

whence $552 - 48 = 504$ lbs. the friction of the rope.

EXPERIMENT XX.

Fixed-engine plane, similar to last experiment; length 2325 feet, height 115 feet, descent nearly uniform, plane quite straight, weight of rope-roll 8960 lbs., ratio of diameter of roll to diameter of axle 10:1; number of sheeves 134, weight 4524 lbs., ratio of diameters 14:1; length of rope 875 yards, $7\frac{1}{4}$ inches circumference, weight 6157 lbs.

Four empty carriages, each weighing 3472 lbs., descended the plane, and dragged the rope after them in 115 seconds.

$$\text{Theorem } G = (3472 \times 4) \times \frac{1380}{27900} = 686 \text{ lbs.}$$

$$\text{and} \quad F' = 686 - \frac{13888 \times 2325}{16\frac{1}{12} \times 115^2} = 535 \text{ lbs.}$$

whence $535 - 65 = 470$ lbs. the friction of the rope.

EXPERIMENT XXI.

Fixed-engine plane, with rope-roll similar to A in the drawing, *Fig.* II. *Plate* III.; length 2892 feet, height 57 feet 7 inches, weight of rope-roll 4500 lbs., ratio of diameter to diameter of axle 10 : 1, number of sheeves 138, weight 5288 lbs., ratio of diameter of sheeve to diameter of axle 14.65 : 1, length of rope 1000 yards, weight 3696 lbs., circumference 5 inches.

d 2·44

3·696 lb

Eight empty carriages, each weighing 2688 lbs., descended the plane, with the rope attached, in 330 seconds.

$$\text{Theorem } G = (2688 \times 8) \times \frac{691}{34704} = 428 \text{ lbs.}$$

$$\text{and} \quad F' = 428 - \frac{21504 \times 2892}{16\frac{1}{12} \times 330^2} = 393 \text{ lbs.}$$

whence $393 - 120 = 273$ lbs. the resistance of the rope.

N.B. The above engine works regularly with eight carriages at a time, and that number of empty carriages is not, in general, found sufficient to draw the rope out from the engine when descending the plane, the engine being erected for the purpose of dragging the loaded

carriages up the plane. In windy weather, and when the rails are not in good order, they are obliged to have recourse to a horse to assist the gravity of the carriages in dragging the rope out. This plane may, therefore, be taken in practice as not of adequate descent to secure a constant passage to that number of carriages down the plane, and to drag the rope after them.

The excess of gravitating force, above the friction of the train,

$$\text{is } \frac{21504 \times 2892}{16\frac{1}{12} \times 330^2} = 35 \text{ lbs.}$$

to effect the descent of the train in the requisite time, which may be sufficient, in favourable weather, but is certainly less than what ought to be allowed for all variations of weather.

EXPERIMENT XXII.

Fixed-engine plane, similar to the above; length 3165 feet, height 42 feet, weight of rope-roll 2018 lbs., ratio of diameter to diameter of axle 10 : 1, number of sheeves 124, weight 4216 lbs., ratio 14.65 : 1; length of rope 1200 yards, weight 3527 lbs., circumference $4\frac{1}{2}$ inches.

Nine empty carriages, each weighing

3080 lbs., run down the plane, and dragged the rope after them in 360 seconds.

Theorem $G = (3080 \times 9) \times \frac{42}{3165} = 367$ lbs.

and $F' = 367 - \frac{27720 \times 3165}{360^2 \times 16\frac{1}{12}} = 325$ lbs.

whence $325 - 144 = 181$ lbs. the friction of the rope.

When regularly at work, this engine drags twelve loaded carriages up this plane, and the rope is taken out again by the empty carriages descending the plane. In bad weather, that number is not sufficient to accomplish it, and a horse is obliged to be constantly kept at the engine, to assist the carriages in overcoming the resistance of the rope. The plane has not an uniform descent, being least in the middle; the line of direction is also a little curved;

The preponderance of gravity is $\frac{27720 \times 3165}{16\frac{1}{12} \times 360^2} = 42$ lbs.

which, in fine weather, effects the descent in six minutes; but, from the circumstance of a horse being required to be kept continually in attendance, it need scarcely be stated, that this preponderance is too little for general utility.

Recapitulation of the preceding experiments of the friction of ropes on inclined-planes.

TABLE II.

Number of experiments.	Description of plane.	Length of plane in yards.	Circumference of rope in inches:	Friction of rope in pounds.	Total amount of pressure upon the wheel, sheeves, and rollers in lbs	Ratio of diminution of rubbing surface by the use of rollers.	Extent of rubbing surface exposed to pressure and friction.	Ratio of friction to rubbing surface and weight.
XIV	Self-acting	715	5	239	12317	16:1	771	1:3.22
XV	Ditto	715	5	250	12317	16:1	771	1:3.28
XVI	Ditto	1302	5	240	10955	15:1	727	1:3.16
XVII	Ditto	1224	5	350	16576	15.4:1	1076	1:3.07
XVIII	Ditto	902	4½	162	8529	16.9:1	503	1:3.10
XIX	Fixed-engine	882	7¼	504	21666	12:1	1810	1:3.19
XX	Ditto	775	7¼	470	17378	12:1	1584	1:3.77
XXI	Ditto	964	5	273	9840	11:1	934	1:3.42
XXII	Ditto	1055	4¾	181	7652	12:1	642	1:3.54

From these experiments, we find that the proportion of the friction of ropes on inclined-planes, when disposed upon sheeves or rollers, amount to about one-third of the respective weights, or pressure of the whole apparatus, put in motion by such rope, supposing the velocity of the surface exposed to the action, or rubbing of that weight, be the same as that of the rope upon the plane;—when the rope is disposed upon sheeves or rollers, the friction is of course diminished by as much as we decrease the velocity of the rubbing parts, compared with that of the rope.—Thus, in Experiment XIV., the ratio of the friction to the weight is as 1:3.22. By placing the weight upon rollers, the velocity of the periphery of which, to the velocity of the circumference of

the axle, or part exposed to rubbing, is as 16:1; we reduce the friction in that proportion, and make it equal to the 51.32 part of the weight, or 12317:239, as shewn in columns five and six of the table; and, in like manner, the friction will always bear different proportions to the weight of the body, according to the diameter of the sheeves or rollers on which the rope or the weight is placed. When the diameter of the axle remains the same, column nine will then show the ratio which the friction bears to the weight, when it is not placed upon sheeves; and my reason for giving the ratio in this manner, was to express it in terms not variable with the size of the sheeves upon which it might be placed, but in terms which remained constant under every variation in the mode of disposing it. Column six shows the whole weight or pressure of the apparatus put in motion when the carriages are descending, and comprehends the weight of the rollers, the rope-wheels, the rope, and its pressure upon the wheel which it winds round. The resistance of the rope, it will be perceived, is greater in the self-acting planes than the fixed-engine planes, which most probably arises from the rope of the former having to bend round the wheel when the carriages are traversing the plane; while, in the latter, the

rope is only uncoiled off the roller, as the carriages drag it out from the engine.

The maximum resistance is nearly the third, and the minimum as 1:3,28. In practice, it will however be sufficiently accurate, and perhaps more adviseable, to take the third. In the fixed-engine plane, the same ratio should be taken; as the engine, in winding the rope upon the roller will be subjected to the same amount of friction that occurs in the self-acting plane, from the bending of the rope. In calculating however upon a descent of plane. that will cause the carriages to drag the rope out from the engine; we may, in favourable circumstances, take the ratio at $3\frac{1}{2}:1$. Assuming, therefore, the ratio as one-third, by causing the rope to run upon rollers, the periphery of which, where the rope is supported, being twelve inches, and the diameter of the axle, on which the roller runs, one inch; then the friction will be diminished in that ratio, and become only the thirty-sixth part of the weight, and in the same proportion with any other size of roller.—And, in general, we can calculate, "*à priori*," the friction of the rope upon any plane, by taking the weight of the whole apparatus, inclined-wheel, sheeves, and rope; and the pressure of the latter upon the wheel, in winding round it, and also its extra

pressure by any curves in the line of the road, then the friction will amount to one-third of the whole of that weight, if no rollers were employed.—Knowing the diminution, by the size of sheeves fixed upon, the actual friction is found.

Having thus ascertained the ratio of the friction to the weight, it will be evident that the friction of ropes of different lengths will be in proportion to those lengths, or to the weight.

The preceding proportion, expressing the resistance of the rope, I trust may be depended upon as a datum of calculation in general; but, in applying it to practice, it must undergo some limitation. It has been ascertained, under favourable circumstances, the planes were not prepared for the purpose; but taken as in actual use, and as they had remained for some years; but, during the experiments, the weather was favourable, and this has considerable effect upon the resistance; we must, therefore, found our calculations upon data which will hold good under every possible variation of weather, and this can only be done by appealing to practice.

In the selection of the planes which I have here given, there is one which I consider just adequate, with the number of carriages usually

employed, to effect a regular and constant passage during all states of the weather, (except under very extraordinary circumstances indeed, such as the rails being covered with snow;) I shall, therefore, make that the foundation of my data for estimating the effects on other planes. — To effect the descent of any carriage or train of carriages down a plane by the action of gravity, we must give a certain excess of preponderance above the friction of the respective parts, to accomplish that descent in a given time; and this time will be entirely governed, and be in precise proportion to the excess of gravitating force employed, compared with the weight of the carriages,

$$\text{being as } W : \frac{W\,S}{r t^2}$$

The self-acting plane, Experiment XIV., is one which, when six loaded carriages are employed in dragging six empty carriages up by the rope there described, I can safely state, from a daily opportunity of witnessing its action, has just sufficient preponderancy to effect the required effect, and I do not think it would be proper in any case to allow less.

The whole weight there moved $= W + w$ will be 69384 lbs., and the excess of preponderance above the friction and resistance of the whole train $G - g + \overline{F + f + \varphi}$ will be equal to 400 lbs. nearly.

Whence we have $\frac{W\,S}{rt^2} = 400$ lbs. or $G - F' = 400$ lbs.

Then, by Theorem E $t = \sqrt{\frac{(W + w) \times S}{(G - F') \times r}} = 152$ seconds.

By Experiment XIV., when the moving force and resistance were in a state of dynamical equilibrium, the time of descent was 200 seconds. In practice as above, we find that in order to effect the certain transit or passage, it is necessary that the preponderance should be such as that, under the most favourable weather, the descent should be effected in 152 seconds; then the excess or preponderance of gravitating power to be given in practice above what is required to merely effect the descent in fine weather, or by taking the resistance as shewn in the table, must be in the ratio of 200 : 152, or in even numbers as 4 : 3.

CHAPTER VIII.

OBSERVATIONS AND EXPERIMENTS ON THE VARIOUS KINDS OF MOTIVE POWER EMPLOYED ON RAIL-ROADS.

This chapter will comprehend practical illustrations of the different species of motive power previously enumerated, deduced from the foregoing disquisitions, and from experiments made on their performances in actual use upon Rail-roads.

For the sake of making a better comparison of their various effects, by classing those following the same laws together, I shall divide them into the following order :—

1. Self-acting planes.
2. Engine-planes.
3. Horses.
4. Locomotive-engines.

I.—SELF-ACTING PLANES.

The impelling force of this kind of motive power is gravity; it is confined, as previously stated, to descending planes alone, and, when employed in practice, their object is to effect

the ascent of a train of carriages by the descent of a similar train more heavily loaded in a given time. The respective weights W and *w* of the descending and ascending train of carriages being given, we shall then have the following known quantities derived from the preceding experiments, viz. F. and *f*, by Table I. page 194, ϕ by Table II. page 214.

Then, taking the friction and resistance of the several moving parts, as deduced by the foregoing experiments, and knowing the time of descent, we shall have for the preponderance of gravity, necessary to effect the passage of the carriages upon the plane in that time,

$$\tfrac{4}{3}\,G - F' = \frac{(W + w) \times S}{r t^2}$$

and, in the case of a single train of carriages dragging a rope after them,

$$\tfrac{4}{3}\,G - F' = \frac{W S}{r t^2}$$

In practice, therefore, we must either elevate the plane, or increase the number of carriages, until we obtain the requisite preponderance; but, in every case, it will be necessary, in order to secure the constant action in winter and summer, that the excess amount to that given by the above formula.

Before dismissing the subject of self-acting planes, it may be necessary to state, that consi-

derable regard should be observed in forming the line into a proper descent, or into that in which the velocity of the carriages, on all parts of it, shall be as nearly equable as possible.

The action of gravity causing bodies to descend with velocities uniformly accelerated, the motion of the carriages upon a plane with a uniform descent will be very variable; moving slow at first, then with an accelerated motion, as the square of the times employed in traversing the plane; and becoming very rapid at the end of the plane. The plane should not, therefore, be made with a regular and uniform descent; but such as, by making the descent more rapid at the top, will give an additional preponderance of gravity at the commencement, and cause the carriages to acquire the requisite velocity; and then, to diminish that descent on the remaining parts of the plane, in such a ratio that the diminution of preponderance will abstract as much gravitating force as, by diminishing the accelerative tendency, will compensate for the increasing velocity of the carriages, by the accelerating force of gravity, so that the two will counteract each other, and thus produce a uniform velocity in the carriages on the plane. The line of descent to perform these conditions is rather difficult to determine, but perhaps will approach somewhat near to that curve called a cycloid.

II.—FIXED STEAM-ENGINES.

To elicit the performance of steam-engines, fixed, and dragging carriages up planes inclined or parallel to the horizon by means of ropes, I have selected the four following experiments on engines that have been in use for some time, and which, I trust, will be sufficient to furnish data by which we may calculate the performance of engines upon other planes.

Not to confine the data to one particular kind of engine, I have taken two low-pressure, or condensing engines, and two high-pressure engines.

EXPERIMENT XXIII.

Boulton and Watt's low-pressure condensing engine, with two 30-inch cylinders, steam $4\frac{1}{2}$ lbs. per square inch above the ordinary pressure of the atmosphere, rope-roller similar to A, *Fig.* I. *Plate* III., rope $7\frac{1}{4}$ inches circumference, same as employed in Experiment XIX.; length of plane 2646 feet, height or ascent 154 feet 6 inches, being the same as Experiment XIX.

Time of drawing up 7 loaded carriages, each weighing 9408 lbs., similar to those employed in Experiments V. and VI., 620 seconds, the engine making 374 single strokes, 5 feet each.

Then $(30^2 \times 2) \times .7854 = 1413.72$ area of cylinders and 1413.72×19.5 the pressure of steam in the boiler $= 27567$ lbs. pressure upon the piston, which, in the experiment, was moved through $374 \times 5 = 1870$ feet; hence $27567 \times 1870 = 51550290$ lbs. moved one foot, the power of the engine.

$$\text{Then } G = \overline{9408 \times 7} \times \frac{1854}{31752} = 3845 \text{ lbs.}$$

Also, by Experiments V. and VI. $F = 43 \times 7 = 301$ lbs.

And, by Experiment XIX. $\phi = 504$ lbs.

Also $\frac{W\,S}{rt^2} = 28$ lbs. the force required to overcome the *vis inertiæ* of the load upon the plane, or to cause it to describe that space in 620 seconds.

Then $3845 + 301 + 504 + 28 = 4678$ lbs. the resistance which, in the experiment, was moved through 2646 feet, whence $4678 \times 2646 = 12377988$ lbs., the resistance moved one foot.

$$\text{Therefore} \begin{cases} 51550290 & \text{power of engine,} \\ 12377988 & \text{effect or resistance,} \end{cases}$$

whence we have the effective power of the engine upon the load, compared with the pressure of the steam upon the piston, equal to 24 per cent.

Velocity of piston, 181 feet per minute,
———— load, 256 feet per minute.

EXPERIMENT XXIV.

Fixed engine, Boulton and Watt's double power, similar construction to the preceding, and same power, viz. with two 30-inch cylin-

ders, steam $4\frac{1}{2}$lb. per square inch above the pressure of the atmosphere, rope $7\frac{1}{4}$ inches circumference, same as Experiment XX; plane the same also; length 2325 feet, height or ascent 115 feet, carriages same as preceding experiment.

Time of drawing 7 loaded carriages 550 seconds, making 320 single strokes of the piston, 5 feet each.

This engine, by an additional rope attached to the end of the above-named train of carriages, also dragged, at the same time, 7 loaded carriages, of the same weight, up another plane in extension of the other; length 770 yards, and height 25 feet 6 inches.

Then $(30 \times 2)^2 \times .7854 = 1413.72$, area of cylinders $\times$ 19.5 the pressure of the steam $= 27567$ lbs. pressure on the piston, which, in the experiment, was moved through $320 \times 5 = 1600$ feet.

Therefore, $27567 \times 1600 = 44107200$ lbs. moved one foot, the impelling power of the engine.

$$\text{Then } G = \overline{9408 \times 7} \times \frac{1380}{27900} = 3264 \text{ lbs.}$$

$$G = \overline{9408 \times 7} \times \frac{25.5}{2310} = 726 \text{ lbs.}$$

And, by Experiment V. $F = 43 \times 14 = 602$ lbs.

Also, by Experiment XX. $\phi = 470$ lbs.

And, by another experiment, not here detailed, $\phi = 127$ lbs.

Also $\frac{W\,S}{r\,t^2} = 31$ lbs. force required to overcome the inertiæ.

And $\frac{W\,S}{r\,t^2} = 31$.

Then 3264 + 726 + 602 + 470 + 127 + 62 = 5251 lbs. the total resistance, which, in the experiment, was moved over 2325 feet; therefore 5251 × 2325 = 12208575 lbs. moved 1 foot, the resistance.

$$\text{Whence} \begin{cases} 44107200 \text{ power of engine} \\ 12208575 \text{ effect produced.} \end{cases}$$

From which we have the effective power, equal to 27.7 per cent. of the pressure of steam upon the piston.

Velocity of piston 174 feet per minute.
———— load 253 feet per minute.

EXPERIMENT XXV.

High-pressure engine; cylinder 21 inches diameter, elasticity of steam in the boiler 30 lbs. per square inch, above the pressure of the atmosphere; length of plane 3165 feet, height 42 feet, being the same as detailed in Experiment XXII. Rope $4\frac{1}{2}$ inches, also the same.

Time of drawing 12 loaded carriages, each weighing 9010 lbs., up the plane, 570 seconds; the engine making 444 single strokes, 5 feet each.

Then $21^2 \times .7854 = 346.36$ area of the cylinder, which × 30 lbs. = 10390.8 lbs. pressure of steam upon the piston, which, in the experiment, was moved through 444 × 5 = 2220 feet; therefore, 10390.8 × 2220 = 23067576 lbs. moved 1 foot, the impelling power of the piston.

Then $G = \overline{9010 \times 12} \times \frac{42}{3165} = 1434$ lbs. the gravity of the load;

and $F = 42 \times 12 = 504$ lbs. friction of the carriages;

also ϕ by Experiment XXII, $= 181$ lbs. resistance of the rope;

and $\frac{W S}{r t^2} = 65$ lbs. force required to cause the load to describe the length of the plane is the time $t = 570$ seconds, supposing it free from friction.

Then $1434 + 504 + 181 + 65 = 2184$ lbs. the resistance, which, in the experiment, was moved through 3165 feet; therefore $2184 \times 3165 = 6912360$ lbs. the total resistance moved 1 foot.

Whence $\begin{cases} 23067576 & \text{power of engine,} \\ 6912360 & \text{effect produced;} \end{cases}$

Which makes the effective power of the engine equal to 30 per cent. of the pressure of the steam upon the piston.

Velocity of piston 234 feet per minute,
——— carriages 333 feet per minute, or 3.78 miles per hour.

EXPERIMENT XXVI.

High-pressure steam-engine, cylinder 16 inches, pressure of steam in the boiler 50 lbs. per square inch, length of plane 2892 feet, height 57 feet 7 inches, being the same as Experiment XXI; rope also the same, 5 inches circumference.

Time of drawing 8 loaded carriages up the plane, each weighing 8624 lbs., 390 seconds;

the engine making 400 single strokes, 5 feet 6 inches each.

Then $16^2 \times .7854 = 201$ area of piston, which, multiplied by 50 lbs., the elasticity of the steam, is 10050 lbs., the pressure of the steam upon the piston, which, in the experiment, was moved through $400 \times 5.5 = 2200$ feet.

Therefore, $10050 \times 2200 = 22110000$ lbs. moved 1 foot, the power of the engine.

And $G = \overline{8624 \times 8} \times \frac{691}{34704} = 1373$ lbs.

Also $F = 40 \times 8 = 320$ lbs.: and, by Experiment XXI, $\phi = 273$ lbs.

Also $\frac{W S}{r t^2} = 81$ lbs. the weight necessary to overcome the *vis inertiæ*.

Then $1373 + 320 + 273 + 81 = 2047$ lbs. the total resistance, which, in the experiment, was moved through 2892 feet; therefore, $2047 \times 2892 = 5919924$ lbs. moved 1 foot, the resistance.

Whence $\begin{cases} 22110000 \text{ the power of the engine,} \\ 5919924 \text{ the effect produced.} \end{cases}$

From which we find the effective power equal to 26.7 per cent. of the pressure upon the piston.

Velocity of piston 338 feet per minute,
——— load 445 feet per minute, or 5 miles an hour.

The same engine was tried with 9 loaded carriages, which were drawn up in 420 seconds.

The resistance in this case would be $G = 1544$ lbs.

$F = 360$ lbs.; $\phi = 273$ lbs. and $\frac{W\,S}{r\,t^2} = 79$ lbs.; which, added together, is 2256 lbs. $\times$ 2892 = 6524352 lbs. moved 1 foot.

Whence $\begin{cases} 22110000 \text{ the power,} \\ 6524352 \text{ the effect;} \end{cases}$

and the effective power equal to 30 per cent.

Velocity of piston 314 feet per minute,

——— load 413 feet per minute, or 4.7 miles an hour.

In this experiment we find a greater effective power produced by applying a heavier load, but the time is diminished in nearly the same ratio.

The relative effective power is $\begin{Bmatrix} 26.7 \\ 30. \end{Bmatrix}$ per cent.

And the velocity - $\begin{Bmatrix} 338 \\ 314 \end{Bmatrix}$ feet per minute

Whence we find the relative performances with respect to time and effect $\begin{cases} 9024 \\ 9340 \end{cases}$

The preceding experiment, shewing the performance of these two kinds of engines, will form a rule for the practical application of similar engines to other planes. The effective power of the high-pressure engines is greater than that of the low pressure, but in these experiments neither exceed 30 per cent. The velocity of the pistons was, however, very great, and this would have the effect of diminishing their performance compared with the elasticity of steam in the boiler, otherwise we might have expected a greater amount of effective power. I shall afterwards,

when treating on the loco-motive engine, enlarge a little more upon the effect of this, in diminishing the performance of these kind of engines.

III.—HORSES.

The power of a horse, or that part of his muscular exertion, which, in travelling, he is capable of applying upon the load, has been variously stated by different authors. It is not the force he is capable of exerting at a dead pull, or for a short period, by which we are to judge of, or estimate, his strength; it is what he can exert daily, and day after day for a long period, without injury to his physical powers, that we are to take as the criterion for practice.

A Rail-road is peculiarly adapted to show the power of a horse, as he is continually employed in overcoming the same resistance, and the inclination of the road in general has little effect upon the power required to overcome the gravity of his own weight.

The following Tables will show different Rail-roads, where horses have been used for some years, and the respective resistances which the inclination of the road and the friction of the carriages presented to the action of the horse.

TABLE III.

Table of the line of road on which one horse travels with six loaded carriages, each weighing 8,540lbs. similar to Experiment IV. *No.* 1.; and returns with six empty carriages, each weighing 2,604lbs. same as Experiment IV. *No.* 7.—Edge-rail, Killingworth Colliery Rail-road, friction loaded carriages 40lbs., empty carriages 14lbs.

Respective distances in feet.	Descent of plane in inches.	Gravity of six loaded carriages down the plane in lbs.	Total resistance, being the difference between the friction and gravity in lbs.	Gravity of the 6 empty carriages up the plane in lbs.	Total resistance, being the gravity and friction together in lbs.
330	6.5	84	156	25	109
330	12.	155	85	47	131
330	16.5	213	27	65	149
330	18.5	239	1	72	156
330	14.	181	59	55	139
330	17.	219	21	67	151
330	18.	232	8	71	155
330	30.5	394	.	120	204
330	44.	569	.	173	257
330	25.5	329	.	100	184
330	2.	25	215	7	91
330	8.	103	137	31	115
330	11.	142	198	43	127
330	24.	310	.	94	178
330	23.5	304	.	92	176
330	0	0	240	0	84
330	14.	181	.	55	139
330	40.	517	.	157	241
330	33.5	433	.	132	216
198	9.	194	46	59	143

On examining the above Table, it will be seen that the average resistance with the load is about 60 lbs.; and in returning with the empty carriages 157 lbs., the mean 109 lbs. —The distance 2156 yards.

The horses were very large and heavy; they

generally traversed that distance eight times a day, being in all about nineteen miles.—There were four horses regularly employed, but it was found necessary to keep a spare horse, to give the others alternately a day's rest; so that, in fact, five horses were kept to perform the constant work of four horses effectively.

TABLE IV.

Table of the performance of horses upon the Backworth Colliery Edge-rail-road, where a horse takes six loaded carriages, each weighing 9,010lbs. down the plane, and returns with six empty carriages up the plane, each weighing 3,080lbs.

Friction of loaded carriages 42lbs. and of empty 15lbs.

Length of plane in feet.	Descent of plane in inches.	Gravity of six loaded carriages down the plane in lbs.	Total resistance in lbs. being the difference between the friction and gravity.	Gravity of six empty carriages down the plane in lbs.	Total resistance in lbs. being the gravity and friction together.
330	15.	204	48	70	160
330	14.5	197	55	67	157
330	7.	95	157	32	122
330	14.5	204	48	67	157
330	5.	68	184	23	113
330	5.5	75	177	25	115
330	18.	245	7	84	174
330	12.5	170	82	58	148
330	16.5	225	27	77	167
330	18.	245	7	84	174
330	31.	423	.	144	134
330	24.5	334	.	114	204
330	38.5	525	.	179	269
330	26.	354	.	121	211
330	20.	273	.	93	183
330	31.	423	.	144	234
330	48.	655	.	224	314
330	40.	546	.	186	276
411	41.5	454	.	193	283

The preceding Table will show the performance of the horses upon a portion of the Backworth Colliery Rail-road; these horses, like those employed on the Killingworth Rail-road, are extremely powerful, as may be presumed. The average resistance with the loaded carriages is 42 lbs., and with the empty carriages 189 lbs., giving a mean of 115 lbs.; they traverse the distance backwards and forwards most frequently eight times a day, making nineteen miles. This Table may be taken as the maximum performance of horses, and will shew the resistance which a very powerful horse is capable of overcoming occasionally.

TABLE V.

Table of the performance of horses upon the Team Colliery Edge-rail-road, where a horse travels with four loaded carriages down the plane in summer, and returns with the same number empty; and with three carriages in both directions in winter. Weight of loaded carriages 8,540lbs. friction 40lbs., empty carriages 2,604lbs. friction 14lbs.

Length of plane in feet.	Descent of plane in inches.	Ascent of plane in inches.	Resistance with four carriages.				Resistance with three carriages.			
			Gravity of the loaded carriages in lbs.	Total resistance down the plane in lbs.	Gravity of the empty carriages in lbs.	Total resistance up the plane in lbs.	Gravity of the loaded carriages in lbs.	Total resistance down the plane in lbs.	Gravity of the empty carriages in lbs.	Total resistance up the plane in lbs.
430	81	.	536	.	163	219	402	.	123	165
500	32	.	182	.	55	111	137	.	42	84
500	68	.	330	.	100	156	248	.	75	117
500	48	.	273	.	83	139	205	.	63	105
500	42	.	239	.	72	128	180	.	54	96
500	50	.	284	.	86	142	213	.	65	107
500	37	.	210	.	64	120	158	.	48	90
500	.	.	.	160	.	56	.	120	.	42
500	.	6	34	194	10	46	26	146	8	6
500	.	32	182	342	55	1	137	257	42	.
500	.	9	51	211	15	41	39	159	12	30
500	3	.	17	143	5	61	13	107	4	46
500	7	.	39	121	12	68	30	90	9	51
500	3	.	17	143	17	73	13	107	13	55
500	13	.	74	86	22	78	56	64	17	59
500	17	.	96	64	29	85	72	48	22	64
500	14	.	79	81	24	80	60	60	18	68
500	23	.	130	30	39	95	98	22	30	72
500	42	.	239	.	72	128	180	.	54	96
500	29	.	165	.	50	106	124	.	38	80
500	19	.	108	52	32	88	81	39	24	66
400	17	.	120	40	36	92	90	30	27	69
600	44	.	208	.	63	119	271	.	48	90
500	34	.	193	.	59	115	145	.	45	87
450	20	.	126	34	38	94	95	25	29	71

The horses employed upon the above Rail-road are not so strong and heavy as those

upon the roads shewn in Tables III. and IV. The average resistance with the loaded carriages is about 70 lbs., and with the empty nearly 100 lbs., making a mean of 85 lbs.—The distance is traversed four times every day, which is nearly twenty miles. In winter, (for about five months in the year,) they are only able to travel with three carriages; though less than the other horses, they are by no means small or light, but what may be termed, moderately-sized. The resistance upon one part of the road with the load, amounts to 342 lbs.; but, as the carriage has previously acquired considerable velocity before it arrives at this part of the road, the momentum will aid the horse in overcoming the resistance, which is only for a short distance.

The average resistance overcome by the horses in Table IV. is 115 lbs., and in Table V. 85 lbs.; taking the former as the effect of the largest horses, and the latter as the effect of smaller, we shall have as the mean 100 lbs., which may be taken as the performance of moderately-sized horses upon level roads, travelling twenty miles a day. If the friction of carriages be reckoned at the 200th part of their weight, Table I., then the weight, which will present a resistance of 100 lbs. upon an Edge-rail-road, will be 20,000 lbs.; as, however, the

resistance of the carriages in winter would be greater than that shewn in the Table, we may perhaps take the power of a horse as equal to 112 lbs., the mean of Tables III. and IV., travelling at the rate of two miles an hour, or twenty miles a day, which, on a level Railroad, would make the weight of goods conveyed equal to ten tons.

Taking then ten tons, moved over the space of twenty miles a day, as the performance of a horse, the effect will be equal to 200 tons one mile; and, as this performance is effected at that pace or velocity which the horse inadvertently falls into himself, we may consider it his maximum effect. I have not in the Tables given the speed at which the horses travelled; that would vary much, according to the resistance presented in the different parts of the road; but the average velocity of Table III. did not amount to more than two miles an hour. And I am inclined to think, from attentively noticing the speed of the horses in the other, at various parts of the road, that the velocity with which they travelled would not be more.

I am not acquainted with any experiments made on the performance of horses, travelling at different rates of speed.—The rapid diminution of their power, from the great portion of

their muscular exertion required to move themselves along, is observable upon the coaches and other vehicles upon the common roads.

To obtain a sort of approximation to the energy of the power of horses at different rates of speed, I formed a kind of rule, on which I founded my calculations. Taking the force when continually exerted for ten hours, travelling at the rate of two miles an hour, or for twenty miles a day, as deduced from the preceding experiments, to be equal to 112 lbs. I made this a general expression, for his accumulated performance.

I found, when a horse travelling with a load was left at liberty to assume what pace he pleased, that heavy horses, such as used in Experiments III. and IV., generally fall into a pace of two miles an hour; and lighter horses, such as in Experiment V., into two miles and a half an hour; I considered these as the paces where the muscular exertion of the horse suffered least in performing a certain quantity of work, and at which his effect would be the greatest, as I invariably found, on pushing a horse at a more rapid rate, he was more distressed in performing the same work. I then took 112 lbs., which, when the friction is equal to the 200th part of the weight, would be ten tons or 200 cwt., multiplied by two miles an

hour $=400$, as the general expression of his performance for twenty miles: and considered that in travelling twenty miles at any other rate of speed, his effect would not be greater; at least, I considered that the extra muscular exertion required to transport his own weight, which is more than seven times that which is exerted upon the load, would be equal to that diminution of weight, which, multiplied into the speed, would make the sum of his effort remain the same, and equal to 400.

Taking this rule, and making $v =$ the velocity in miles per hour, we have 224 lbs. as the effort of a horse at one mile an hour, and $\frac{224}{v}$ his effort at any other rate of speed; or, making 400 as the expression of his performance of the weight multiplied into the velocity, we have $\frac{400}{v}$ as the weight which he will drag upon a level Rail-road at any other velocity.

Since forming my calculations, I find Professor LESLIE, in his Elements of Natural Philosophy, had previously given a formula for calculating the force which a horse can exert upon the load at different rates of speed.

He states, "with regard to the power of draught, the formula $(12-v)^2$, when v denotes the velocity in miles an hour, will perhaps be found sufficiently near the truth.—Thus, if a horse beginning his pull with the force of

144 lbs. would draw 100 lbs. at a walk of two miles an hour; but only 64 lbs. when advancing at double that rate, and not more than 36 lbs. if he quickened that pace to six miles an hour; his greatest performance would hence be made with the velocity of four miles an hour."

The above rule, I find, has been lately adopted by some writers on the subject; but having previously formed my calculations from the other, and as it does not materially differ from that given by Professor LESLIE, up to that rate of speed at which horses are generally made to travel; I shall not now alter them, but shall in the Table below give the respective weights by each formula, which the reader will have an opportunity of comparing together.

TABLE VI.

Miles per hour	Force exerted upon the load in lbs. by the formula $\frac{224.}{v.}$	Load which a horse can draw upon a level rail-road in cwts. by formula $\frac{400}{v}$	Force exerted upon the load in lbs. by Professor Leslie's formula $(12-v)^2$	Load which a horse can draw upon a level rail-road by Professor Leslie's formula.
2	112	200	100	180
3	74⅔	133⅓	81	144
4	56	100	64	114
5	44⅘	80	49	88
6	37⅓	66⅔	36	64

Columns 3 and 5 are calculated on the supposition that the friction is equal to the 200th part of the weight, and that the horse travels 20 miles a-day.

IV.—LOCO-MOTIVE ENGINES.

In my investigations respecting loco-motive engines, I shall confine myself wholly to those which effect their progressive motion by means of the adhesion of their wheels upon the rails; the only engines of that kind at present in use which do not, are those of Mr. Blenkinsops, at Leeds, with the rack-rail; and as I have not had any opportunity of ascertaining their performance by the test of experiment; I shall not, therefore, attempt to give any opinion of their utility, compared with the other, founded only on report or on bare supposition.

I have before explained the nature of the action of the engine-wheels upon the rails; and the principle by which the loco-motion is effected; the great importance of knowing the precise amount of that adhesion, whereby we may be able to calculate, with certainty, upon what inclination of road, and with what number of carriages, the engines can effect their progressive motion, will be very evident, as, upon that, the whole system of their action is regulated.

This may either be ascertained by continued observation of their performance upon

certain lines of roads; or, it may be made the subject of direct experiment. The great variation in the amount, arising from the surface of the rail presenting more or less adhesion to the wheels, in different states of the weather, renders it difficult to subject the engines to experiments at all the various changes; and almost compels us to have recourse to the two extremes in order to obtain a mean result. I shall, therefore, give the particulars of two experiments, one in the most favorable, and the other in the most unfavorable state of the rails.

When the surface of the rails and wheels are either quite dry or completely wet, the adhesion is the greatest, the surface being then most free from the presence of all extraneous matter; when the rails, on the contrary, are moistened with wet, and partly covered with mud, the adhesion is the least: the mud interposing between the surface of the wheel and rail, diminishes the adhesion very considerably, in the same manner as oil or grease applied to the bearings of shafts, or other rubbing surfaces, reduces the friction. In all the intermediate states of the rail the adhesion varies, and in greater or less proportion, according as that state approaches more or less toward either of these changes.

It will be evident, that the total amount of adhesion is that force which would be required to cause the engine to slide along by its wheels upon the rail, if the wheels were prevented from turning round; or that amount of force compared with its weight, which the friction of other rubbing surfaces bear to their weight. Knowing, then, the friction of iron sliding on iron, and the weight of the engine, we could deduce the amount of adhesion of an engine, compared with its weight; or, by fastening the engine-wheels, and employing a force to drag the engine, loaded with different weights along the Rail-road, we could, by this mode, ascertain the amount of adhesion proportionate to the weight; either of these, though very correct modes of ascertaining the total amount of adhesion, compared with the weight, would not, perhaps, be so accurate a standard for practical application. The force of the steam, at different periods of the stroke, being very irregular upon each wheel, might occasion the result, in practice, to vary from that deduced by the foregoing methods.

EXPERIMENT XXVII.

Loco-motive engine, weighing $6\frac{1}{2}$ tons, and containing 1 ton of water, $= 7\frac{1}{2}$ tons, dragged 12 loaded carriages, each weighing 9408 lbs.,

up a plane ascending 134 inches in 1164 feet, and also the convoy-carriage, weighing $1\frac{1}{2}$ tons, the wheels not slipping. Rails quite dry. Edge-rail $2\frac{1}{2}$ inches broad at the top.

Then, weight of the engine 16800

12 carriages $= \overline{9408 \times 12} = 112896$

Convoy-carriages $\frac{3360}{133056} \times \frac{134}{13968} = 1277$ lbs. gravity

Friction of 12 carriages, at 43 lbs. each - $=$ 516

Friction of convoy-carriage - - $=$ 17

1810 lbs. the total resistance overcome by the engine, (exclusive of the power required to propel itself forward); and, consequently, the adhesion of the wheels upon the rails, when the surface of the rails are dry.

EXPERIMENT XXVIII.

Same engine, with 29 empty carriages, each weighing 3472 lbs., up an ascent of 1 in 324; rails slightly covered with mud, and in the worst state; wheels slipped a little, but the engine proceeded at the rate of about 4 miles an hour.

Then, as before, $16800 + 3360 + \overline{3472 \times 29} = 96128 \times \frac{1}{324} =$ 296 lbs. the gravity of the engine and carriages. Friction of carriages $29 \times 16 = 464 + 17 = 481$ lbs.; which, added to the gravity, gives $481 + 296 = 787$ lbs., the adhesion in the worst weather.

This latter should, of course, be taken as that resistance with which the engine should

be loaded; and this would be sufficient to drag about 70 tons upon a level road. The engine-wheels, however, as stated in the experiment, slipped a little, and though the progressive motion was notwithstanding kept up, yet such a slipping of the wheels would have a very injurious effect, not only upon the wheels, but also to the rails. The load should not, therefore, be so great as to produce such an effect.

From several years' observation of their performance upon the Killingworth Rail-road, I am inclined to think the above rather too high, without incurring the risk of slipping. There, they travel sometimes with 9 and sometimes with 12 carriages, amounting to 36 and 48 tons respectively. The greatest ascent, upon any part of the Rail-road with the load, is 1 in 330; and in returning, with the empty carriages, 1 in 80. The wheels, in very bad weather, slip sometimes with 12 carriages; but the engines, in the worst weather, are never prevented travelling with 9 carriages.

Taking the latter as the datum, we have 8764 lbs. the weight of each carriage $\times 9 \times \frac{1}{330} = 61$ lbs., the gravity of the carriages. And $\overline{16800 + 3360} \times \frac{1}{330} = 239$ lbs., the gravity of the engine and convoy. Then $9 \times 40 = 360$ lbs., the friction of the carriages, and 17 lbs. the friction of the

convoy. Whence $61 + 239 + 360 + 17 = 677$ lbs., the resistance which the engine is capable of overcoming by the adhesion of the wheels at all times upon an Edge-rail-road without slipping.

The weight of the engine is about 16,800 lbs., *whence the amount of adhesion will be equal to the 25th part of the weight;* and, as the friction or adhesion will always be in proportion to the pressure upon the rails, this expression will be constant, and will apply to engines of different weights.

Having thus ascertained the proportion which the power that enables the engine to effect its progressive motion bears to its weight, we can easily calculate the acclivities, which, with certain weights, will present resistances corresponding with this power. Thus, upon a level plane, the engine will overcome a resistance the amount of which is equal to the 25th part of its weight; or taking the friction of carriages the 200th part of their weight, a load equal to $\frac{200}{25}$ of its weight. If the acclivity of the plane, on which the engine is made to travel, be such, that the height is equal to the 25th of its length; then the whole adhesion of the engine will be required to drag itself forward, and none will be left for the load; and, in all the intermediate degrees of elevation, between a dead level and

the above inclination of plane, the amount of adhesive power, which the engine can spare to the load, above that required to propel itself forward, will be inversely as the sine of the angle of inclination, or as the height of the plane to its length.

The above will give the limits to which the nature of their action restricts the application of this kind of engines, and will shew upon what inclination of road they can be used: this will of course vary with the weight of the engine, and the load which it has to overcome; but, in every case, making K = the weight of the engine. If the total resistance, arising either from the gravity of a certain elevation of plane, or from the friction of the carriages, or from both combined, do not exceed $\frac{K}{25}$, the adhesion of the wheels will be sufficient to enable the engine to effect a progressive motion in all states of the weather without slipping.

The leading object of all machines, especially of this kind, is to perform a definite quantity of work in a given time: to do this with the least expenditure of power, there will be in every case a certain load compared with the weight of the engine, which, when used, will make the performance a maximum: it will, however, be impossible to ascertain this, without a perfect knowledge of all

the phenomena of their action, and this again, perhaps, cannot be ascertained without subjecting them to the test of experiment. Observation and experience may guide us in forming a judgment of the performance of any engine, but it is only by subjecting them to experiments in all their various modes of action, that their general law of action is developed.

To accomplish this, I commenced a series of experiments on the Killingworth Rail-road, with the engines there used; and, by applying different engines with the same load, and also the same engine with different loads, I was enabled to ascertain, with nearly perfect accuracy, the relative performances both with respect to weight, and also to velocity.

With the expectation of reducing the friction, and also to obtain the performance at different rates of speed, I affixed larger travelling-wheels to the engine, and, by experimenting upon the same engine, with different-sized wheels, I was not only enabled to prove the relative performances of wheels of different diameters, but also to ascertain the actual amount of friction inherent in the engine itself.

The following Tables will shew the result of these experiments.

Account of some Experiments made on the performance of loco-motive engines upon the Killingworth Rail-road.

Length of plane 2260 yards, with an ascent in one direction of 6 feet 5 inches, not uniform, varying from a dead level, or slightly undulating, to an ascent, in one place, of 1 in 330—Edge-rail $2\frac{1}{2}$ inches broad on the surface; carriages all the same construction, weighing $81\frac{1}{4}$ cwt. each, wheels 34 inches diameter, axles $2\frac{3}{4}$ inches diameter.

No. I.—Loco-motive engine of the construction represented in *Fig*. 1 and 2, *Plate* V., length of boiler 8 feet, diameter 3 feet 9 inches, diameter of tube in which the fuel is placed 20 inches, with two cylinders 9 inches diameter each; wheels of different diameters, as explained in the following Table; steam 50 lbs. per square inch.

TABLE VI.

Number of Journies.	Experiment XXIX. 8-feet wheels, 9 carriages, weighing 731¼ cwt.				Experiment XXX. 4-feet wheels, 9 carriages, weighing 731¼ cwt.				Experiment XXXI. 4-feet wheels, 12 carriages, weighing 975 cwt.			
	up the plane		down the plane		up the plane.		down the plane.		up the plane.		down the plane.	
	Time in min.	Strokes per min.	Time in min.	Strokes per min.	Time in min.	Strokes per min.	Time in min.	Strokes per min.	Time in min.	Strokes per min.	Time in min.	Strokes per min.
1	23	31	18	40	19	28	16	34	16	34	16	34
2	22	33	18	40	16	34	16	34	20	27	16	34
3	22	33	19	38	16	34	17	32	18	30	14	38
4	22	33	16	45	16	34	15	35	17	32	16	34
5	27	27	18	40	16	34	14	38	16	34	14	38
6	22	33	16	45	16	34	14	38	16	34	14	38
7	26	28	20	36	17	32	14	38	17	32	15	35
8	25	28	19	38	14	38	12	45	18	30	15	35
9	22	33	19	38	14	38	13	41	17	32	13	41
10	25	28	19	38	16	34	13	41	—	—	—	—
11	19	38	20	36	17	32	16	34	—	—	—	—
12	21	34	20	36	17	32	15	35	—	—	—	—
13	21	34	18	40	16	34	14	38	—	—	—	—
14	20	36	18	40	16	34	13	41	—	—	—	—
15	—	—	—	—	16	34	11	49	—	—	—	—
16	—	—	—	—	13	41	12	45	—	—	—	—
17	—	—	—	—	15	35	14	38	—	—	—	—
18	—	—	—	—	16	34	13	41	—	—	—	—
19	—	—	—	—	16	34	13	41	—	—	—	—
	317	32	258	39	302	34	265	39	155	32	133	36
	Distance traversed, 36 miles in 9 hours 35 min.; coals consumed 2,534 lbs.; water 890 gallons.				Distance traversed, 48.8 miles in 9 hours 27 min.; coals consumed 2,534 lbs.; water 854 gallons.				Distance traversed, 23 miles in 4 hours 48 min.; coals consumed 1,546 lbs.; water 452 gallons.			

No. II.—Loco-motive engine, similar construction as the preceding, except in the dimensions of the boiler and tube. Length of boiler 9 feet 2 inches, diameter 4 feet, and diameter of tube 22 inches, cylinders each 9 inches, wheels as per following Table, steam 50 lbs. per square inch.

TABLE VII.

Number of journies.	Experiment XXXII. 3-feet wheels, 9 carriages, weighing 731½ cwt.				Experiment XXXIII. 4-feet wheels, 12 carriages, weighing 975 cwt.			
	Up the plane.		down the plane.		up the plane.		down the plane.	
	Time in min.	Strokes per min.	Time in min.	Strokes per min.	Time in min. sec.	Strokes per min.	Time in min. sec.	Strokes per min.
1	17	42	16	45	11.40′	34	9.4′	44
2	20	36	18	40	9.20′	43	8.5′	49
3	21	34	18	40	8.22′	47	7.40′	51
4	21	34	18	40	8.16′	48	7.42′	51
5	23	32	18	40	8.10′	49	7.55′	50
6	23	32	18	40	—	—	—	—
7	21	34	18	40	—	—	—	—
8	21	34	18	40	—	—	—	—
9	23	32	19	38	—	—	—	—
10	22	33	19	38	—	—	—	—
	212	34	180	40	45.48′	43	40.26′	49
	Distance each journey 2260 yards. Total 26 miles; ascent 6 feet 5 inches; time 6 hours, 32 min.; coals consumed 1487 lbs.; water 490 gallons.				Distance each journey 2002 yards. Total 11.375 miles; distance passed over in the above time, 1663 yards each journey, or 9.45 miles; time 1 hour 26 min. 14 sec.; coals consumed 587 lbs.; water 200 gallons.			

The preceding experiments were made upon a piece of Rail-road, with a nearly uniform inclination; the rails were not of the most modern construction, and would, therefore, in some places, present considerable obstruction to the

wheels of the carriages. The experiments were performed with the strictest regard to accuracy; the coals were measured by a standard coal-tub, strike measure; and, to be certain with regard to the weight, several tubs were also weighed, and the difference of weight, which was scarcely worth noticing, averaged. The water was also carefully measured.

In the first four experiments, the time was marked when the engine began to move from the end of the plane, so that the force required, and also the delay taken up in putting the carriages into motion, was included. No attempt was made to augment the speed of the engine to the greatest that could be performed; my object being to ascertain the relative performances with different wheels and different loads. I therefore endeavoured to keep up a speed as equable as possible, and, in doing so, I had frequently to regulate and check the velocity to obtain the same number of strokes per minute in each experiment.

In the fifth experiment or XXXIII, the engine was allowed to traverse a given space, to put the train of carriages into their proper velocity, before the time was noticed; the time was then marked until the velocity was again checked at the farther end of the stage. This will explain the difference between the two distances mentioned in that experiment; the one was, the

whole distance from the commencement to the end of the stage; the other was, that part of the stage which the engine passed over, when the regular velocity was acquired, and before it was again diminished at the end of the stage, to stop the train; the time given in the Table was that which transpired while the engine was passing over that space, while the velocity was uniform; and may, therefore, be taken as a measure of speed.

Experiments XXIX and XXX were made, to ascertain the effect with wheels of different diameters. The engine was the same in each experiment; the only alteration made, was taking the 3-feet wheels from off the axles of the engine, and replacing them with wheels 4 feet diameter. The stage was the same, and every care was taken to make the experiment an accurate comparison of their relative effects.

Consumption of coals and weight propelled remained the same.

No. I. Engine	3-feet wheels	traversed the respective distances of	36 miles
	4-feet wheels		48.8 miles;

Whence we find, that, with a given quantity of fuel, the distance traversed by the engine, with different-sized wheels, is in the ratio of the diameter of these wheels, when the load is the same in both cases.

The consumption of fuel, when every cir-

cumstance remains the same, being as the space passed over; then, as 63280 yards, the space passed over in Experiment XXIX : 2534 lbs. the coals consumed : : 85880 yards, the space passed over in Experiment XXX : 3439 lbs. the coals which would have been consumed in Experiment XXIX in traversing 85880 yards; the relative consumption of coals will then be

No. I. Engine	3-feet wheels	distance and load the same in each Experiment,	3439 lbs.
	4-feet wheels		2534 lbs.

From which we have the relative consumption of fuel by the same engine, with 3 and 4 feet wheels, as 3439 : 2534, which is nearly in the inverse ratio of their respective diameters.

It may appear paradoxical to some, that, by increasing the wheels, the engine was enabled to pass over a greater distance without any loss of effect; and might lead to a supposition, that by making the wheels extremely large, it might travel with very little power at all; but, when duly considered, it will prove very consonant with reason, and what, from the nature of the action of these machines, we might have been led to expect.

Before, however, explaining this, it will be necessary to ascertain the amount of the whole retarding forces opposing the motion of the engine, viz. the friction of the engine, and the

friction of the carriages. The latter I have previously shewn; I shall, therefore, give an experiment made to ascertain the former.

EXPERIMENT XXXIV.

Upon the same plane or piece of Rail-road described in Experiment V., with a descent of 11 feet 2 inches in 388 yards, I allowed 5 loaded carriages, each weighing 9408 lbs., to descend freely, as explained in that experiment, which they performed in 120 seconds. I then had them drawn up the plane again, and attached the engine to them, shutting off the communication between the boiler and the cylinders; so that the steam could not act upon the pistons, either to accelerate or retard the motion of the engine; the top and bottom of the piston being alternately open to the atmosphere; the only obstruction to the motion of the engine down the plane was then the friction of the various moving parts. The carriages and engine was allowed to descend the plane freely, which occupied 150 seconds, making the obstruction of the engine, to the gravitating force of the waggons, equal to 30 seconds.

The weight of the engine and convoy-carriages together was 9 tons = 20160 lbs., and the carriages 9408 × 5 = 47040 lbs., making together 20160 + 47040 = 67200 lbs.

Then the retardation, caused by the friction of the whole, will be

Theorem (B) $F = G - \frac{WS}{rt^2} = 428$ lbs., the friction of the engine and carriages. By Experiment V. we have the friction of the carriages $43 \times 5 = 215$lbs.; whence $428 - 215 = 213$ lbs., the friction of all the moving parts of the engine.

The resistance of the engine, when moved along, and not subjected to the pressure of the steam, will then be 213 lbs.; of this, taking the friction at the 200th part of the weight, 100 lbs. will belong to the axles and the action of the wheels upon the rails, leaving 113 lbs. as the friction of the pistons, connecting chain, and other rubbing parts of the engine.

The total friction, however, when employed in dragging a load after it, or that part of the power required to produce a progressive motion in the engine itself upon the road, when loaded will be different, and will be greater than when the simple motion of its parts only are concerned. When loaded with a certain resistance, the whole of that weight or pressure has to be transmitted from the impelling to the impelled part of the engine, or from the pistons to the wheels upon the rail, through all the intermediate parts; and this pressure, acting upon all the various parts of the engine, forming the connection between these two points, will

necessarily produce friction, and, consequently, add to the resistance; and this will be greater when the engine is heavy, than when lightly loaded, being in proportion to the pressure thrown by the load upon all these intermediate parts.

The total amount of friction will, however, depend upon the extent and number of the moving parts, and the quantity of rubbing surface caused by one rotation of the engine-wheels; and this will be always the same, in one revolution of these wheels, or in one complete stroke, whatever be the progressive motion of the engine in that revolution, except what arises from the rolling of the wheels upon the rail.

Suppose, now, instead of the engine proceeding 9 feet during one complete stroke, or in one revolution of the wheels, the space passed over be 12 feet, then the amount of friction arising from all the moving parts of the engine is the same in each, while the progressive motion is as 12 : 9. The quantity of friction, therefore, compared with the progressive motion of the engine, will then be diminished in that ratio, by using wheels of the diameter of 3 and 4 feet respectively; and the effect of the engine will consequently be proportionably increased.

Let us take the first two experiments in the Table VI.; every circumstance remained the same, except the wheels. The engine, with a like weight of fuel and load, travelled 48.8 miles with 4-feet wheels, in the time that the same engine travelled 36 miles with 3-feet wheels, or the quantity of fuel in travelling the same distance was as 3439 : 2534.

Now, as the weight of fuel consumed will be a measure of the quantity of steam, and, consequently, of the power expended in propelling the load, we can then, from the quantity of fuel consumed in the different cases, determine the total amount of resistance.

With 4-feet wheels the weight propelled by the engine was 731 cwt. and the quantity of coals consumed was 2534lbs.

With 3-feet wheels, the weight was 731 cwt. and the coals 3439lbs. Then, as 2534 : 3439 : : 731 : 992 cwt. the load which would have been propelled by the 4-feet wheels, with the fuel used by the engine with 3-feet wheels, —the load which the latter took was, however, 731 cwt.; hence, the adoption of 4-feet wheels would admit of an increase of load equal to 992—731=261 cwt. The friction of 731 cwt., or 9 loaded carriages, is known to be 360 lbs.; therefore, as 731 : 360 : : 261 : 128 lbs. the diminution of friction by the use of the 4-feet wheels.

This reduction, in the amount of friction, is

therefore produced by the diminution of all the rubbing parts of the engine, compared with the progressive motion. In travelling 48 miles with the 4-feet wheels, the same number of revolutions of the engine-wheels, and consequently the same extent of rubbing action occurs, as before took place in travelling 36 miles with 3-feet wheels: and hence we find the consumption of coals nearly the same in performing both journies.

From the diminution of friction, by the increase of one foot in the diameter of the wheels, we therefore find the whole friction of the engine.

The ratio of the wheels were as 3 : 4, therefore, by the application of 4-feet wheels, one-fourth of the friction in passing over the same space will be annihilated; whence 128 × 4= 512*lbs. the total amount of friction with the 3-feet wheels,* and as 4 : 3 : : 512 : 384 *lbs. the friction of the engine with 4-feet wheels.*

We see, therefore, the reason why the same quantity of fuel produced different effects with 3 and with 4-feet wheels; in the former, the friction was 512 lbs.; increasing the wheels to 4 feet, diminished that friction 128 lbs.; and this diminution of friction amounts to more than the resistance of 10 tons upon a Rail-way, which enables the fuel to produce a corresponding increase of effect.

By further enlarging the diameter of the wheels, however, a corresponding increase of effect will not take place, because the reduction of friction will then only be in the ratio of the diameter of the wheels upon the diminished friction of the engine, or to one-fourth of 384 lbs., and this too will only take place if the construction of the engine be not altered. If the diameter of the axles be increased, so as to compensate for the additional strain by large wheels, the extent of rubbing surface will be thereby also increased, and the diminution lessened accordingly; but, as this increase would form only a small part of the whole friction, the use of large wheels to effect an increase of velocity in the engine will always be of great advantage.

My next object was to ascertain the consumption of fuel, both as regards its absolute quantity, and also the comparative quantity with different loads.

An inspection of the result of the experiments given in the Tables will shew this; but, as it will be found that the quantity varies much, it may be necessary to enter a little more into detail respecting the cause of such variation; and this explanation will also be the means of shewing a very important discovery in the construction of engines for diminishing the quantity of fuel.

The experiments were made with two engines, which I have termed No. I. and No. II.; the first forming the experiments of Table VI, and the latter of Table VII. The construction of both engines were precisely the same, except in the size of the tube which passes through the boiler; no part of the boiler itself, as will be seen on examination of the drawing, is exposed to the direct action of the ignited fuel; a tube is put through the boiler, within which, upon grate bars, the fuel is placed, and, in this manner, the heat is communicated to the water in the boiler. The extent of surface of the water exposed to the direct action of the fire, will then be equal to the semi-periphery of this tube. In the No. I. engine this tube was 20 inches diameter; and, in the No. II. engine, 22 inches diameter; and, except a corresponding difference in the size of the chimney, the two engines were, in every other respect, the same.

Comparing Experiment XXIX with XXXII. where the same load was taken, we find the quantity of fuel consumed by the former, in travelling 63280 yards, to be 2534 lbs., and, in the latter, for travelling on the same ground, 45200 yards, equal to 1487 lbs. Then, as 63280 : 45200 : : 1487 : 2101 lbs. Therefore, the relative consumption of fuel by the two

engines, in producing the same effect, is as 2534 : 2101, which shews the saving of fuel, by increasing the surface of the water exposed to the action of the fire, in the ratio of 32 : 40.

Knowing this, it need scarcely be added, that, in every case, the consumption of fuel in these engines will, in some measure, depend upon the extent of surface exposed to the action of the fire. This, no doubt, arises from the intensity of the heat necessary in narrow tubes to keep up a constant supply of steam, producing a more rapid combustion of the fuel and throwing it off imperfectly consumed. In wider tubes, the intensity is diminished, and the fuel undergoes a more perfect combustion, and thus produces a greater effect.

The knowledge of this fact will unquestionably lead to a further diminution in the consumption of the fuel, even in the same engines. It would not, therefore, perhaps be treating the subject fairly, to fix at present the basis of actual consumption for the performance of a definite quantity of work; as, however, the ratio of saving can at any time be applied to any particular quantity fixed upon, I shall, consequently, give the result of the consumption, as deduced by the foregoing experiments; but, first of all, I shall ascertain the relative quantity with different loads.

Comparing Experiments XXX. and XXXI., which were performed by the same engine, and under precisely the same circumstances, except the load, which, in the former, was with 9 carriages, weighing 731¼ cwt., and, in the latter, with 12 carriages weighing 975 cwt., the consumption was with 9 carriages in travelling 85880 yards 2534 lbs., and with 12 carriages 1546 lbs. in travelling 40680 yards. Then, as 85880 : 4680 :: 1546 : 3263 lbs., which would have been consumed in conveying 12 carriages 85880 yards. Therefore, the relative consumption of fuel, with 9 and 12 carriages, is as 2534 : 3263.

We have previously ascertained the friction of the engine to be 384 lbs., and the friction of each of the carriages to be equal to 40 lbs. each.

Then $384 + \overline{40 \times 9} = 744$ lbs., the resistance of the 9 carriages and engine. And $384 + \overline{40 \times 12} = 864$ lbs., the same with 12 carriages, which makes the respective resistances as 744 : 864. Now, as 2534 : 3263 :: 744 : 958 lbs., so that the consumption of fuel is greater in the ratio of 958 : 864 than the direct increase of resistance by the friction of the additional load.

It was, however, before stated, that the transmission of an increase of resistance through all the working parts of the engine would create an additional degree of friction, and this will, perhaps, partly account for the consumption of fuel increasing in a greater ratio than the simple resistance directly, though the different states of the rail will frequently have a greater effect than this upon the consumption of fuel.

Comparing these with the experiments on

No. II. engine, we have, making the distance the same in each experiment, viz.

As 20020 : 45200 :: 587 : 1325 lbs. consumed by Experiment XXXIII. in traversing the same distance as Experiment XXXII. The two were performed with wheels whose respective diameters were as 3 : 4, but it has been before shewn that the effects are in the inverse ratio of the size of the wheels; we then have 4 : 3 :: 1487 : 1115 lbs. the weight of fuel which would have been consumed by Experiment XXXII., if 4-feet wheels had been used. The relative quantities with 9 and 12 carriages will, therefore, be as 1115 : 1325; the relative resistances, as above stated, were as 744 : 864; therefore, as 1115 : 1325 :: 744 : 876, the resistance which the quantity of fuel consumed in the experiment would have overcome, the direct resistance is 864; so that the consumption of fuel, by experiment, is only greater in the ratio of 876 : 864 than the direct amount of the friction of the engine and load.

This ratio being so very nearly equal, and as the variation of resistance, by the different states of the rail, will frequently amount to more than this, we may, in practice, take the Experiment XXXIII. as the datum for the absolute quantity of fuel, and assume *the relative consumption with different loads as proportionate to the respective resistances presented by the friction of the load, added to the friction of the engine.*

By taking this experiment as a datum, we proceed on sure grounds, as being nearly the

maximum load, for, if any diminution of friction takes place in the engine, when employed in dragging a lighter load, the consumption of fuel will be more than proportionably reduced; and, though against the effect of the engine, will be the safe side in practice.

The consumption of coals in Experiment XXXIII. was 587 lbs. for conveying 975 cwt. of goods, exclusive of the weight of the engine and convoy-carriage, 20020 yards upon a horizontal plane.

Reducing this to the consumption per mile, viz.

As 20020 : 1760 :: 587 : 51.55 lbs., the fuel consumed per mile in conveying 975 cwt.; the resistance of 975 cwt., as before stated, is 480lbs. and the friction of the engine 384 lbs.; therefore, the quantity of coals consumed, in overcoming a resistance of 480 + 384 = 864 lbs. for a mile is 51.55lbs.

Let P = the friction of the engine = 384 lbs.

R = the friction of any number of carriages which may be taken as the 200th part of their weight;

Then, as 864 lbs., the friction of the carriages conveyed 1 mile, : is to 51.55 lbs. the coals consumed in conveying those goods a mile, as per experiment; :: so is $P + R$, the resistance of any other number of carriages and engine : to

$$\frac{51.55 \times \overline{R + P}}{864}$$

the quantity of coals required to convey any given weight of goods, whose friction or resistance is equal to R, the distance of one mile upon a level Edge-rail-road.

The formula $\frac{51.55 \times \overline{R+P}}{864}$ will then represent the consumption of coals with any load R, and if by a further

diminution in the consumption of the fuel, the quantity per mile be reduced below 51.55, then the diminished quantity can be substituted in its stead, and the formula will still represent the quantity with different loads.

The reader will scarcely expect that I should again recur to the subject of friction, after the experiments already detailed. It may appear however, to some, and I know it has already been made the subject of discussion, that, when the steam in the boiler is of a degree of elasticity equal to 50lbs. per square inch of surface, that, in estimating the power of the engine, the same degree of pressure should be calculated upon the surface of the piston; and that the difference between the amount of such pressure, and the actual performance of the engine, is the measure of the friction, or, as it is termed, of "the power lost." I must confess the difference between the two effects at first appeared great; but, on considering the method by which the steam is transmitted from the boiler to the cylinders, and by also subjecting the engine to experiment, the cause soon became very evident; and, when I found that the same law operated in other high-pressure engines, the reason could then no longer be the subject of mystery.

In all high-pressure engines, acting solely by the elasticity of their steam; and, indeed, in

all elastic fluids whatever, when those fluids are subjected to great degrees of pressure, and are thus made highly elastic, there is a tendency in them to resume their original elasticity, or the density of the surrounding atmosphere.

Steam, when confined, may be highly elastic, from the continual addition of successive particles produced in the evaporation of water; and air, from the expansion or compression of the same particles; but the law of their elasticity, when subjected to pressure, remains the same, and each has the same tendency to expand, when the pressure which keeps them in that state is removed.

When, therefore, an aperture is made in a vessel or boiler, containing steam highly elastic, the tendency which fluids of different densities have to assume a state of equilibrium, will cause the steam in the boiler to rush out into the atmosphere; and the velocity of efflux will be proportionate to the difference between the density of the steam in the boiler, and that of the space into which it rushes.

It is a well-known law of pneumatics, that air rushes into a void with the velocity which a heavy body would acquire by falling from the top of a homogeneous atmosphere; and that the velocity with which a fluid of greater den-

sity rushes into another fluid of less density, is as the respective densities of the fluids.

It is in this manner that the steam of the high-pressure engines acts in its passage from the boiler to the cylinders; a passage is made between the two, the area of which is made greater or less by opening or shutting the throttle-valve by means of a regulator; when this opening is made, the steam issues through it into the cylinder with a force proportionate to its density, and, expanding itself, would make its escape into the air, if not prevented by the intervention of the piston.

If now the piston be made to move up and down with a velocity equal to the rate of efflux, then the steam will exert no pressure upon it at all; and, the nearer the two velocities approach towards each other, the less effective pressure will be exerted upon the piston. Again, if the piston be subjected to a certain pressure by the intensity of the load, then the rate of efflux or velocity with which the steam will issue through the regulator, will be proportionate to the difference between the elasticity or pressure of the steam in the boiler, and the intensity of pressure upon the piston, and the velocity of the piston will then be proportionably reduced; and that velocity will be in the precise

ratio of the intensity of the two pressures, and will continue to be diminished as they approach more and more towards the same; and, when they become equal, the piston will not be moved at all. In all these cases, the reader will perceive that the elasticity of the steam in the boiler and that in the cylinder are widely different; the one being that indicated by the pressure on the safety-valve of the boiler, and the other by the intensity of the load upon the piston.

We have all along supposed the production of steam in the boiler to be a constant regular supply, and adequate to form steam in sufficient quantity to keep up the same degree of density in the boiler, whatever be the rate of efflux into the cylinder by the different velocities of the piston. But, if this is not the case, if the formation of steam in the boiler be not equal to the quantity escaping through the throttle-valve, then the density in the boiler will be diminished, and the rate of efflux, and consequently the velocity of the piston, will also be proportionably lessened.

Two causes thus operate in limiting the velocity of all high-pressure engines, viz. the intensity of the pressure upon the piston compared with that in the boiler; and the quantity of

steam produced;—and both these operate in bringing the engine into a state of uniform velocity.

We might indeed, by enlarging the aperture between the boiler and the cylinder, increase the velocity of efflux, and consequently that of the piston; but this would again be rendered futile if the supply of steam could not be kept up; the latter will, therefore, be the principal regulator of the velocity.

We thus see why the same engine is capable of producing very different effects, when employed in dragging different weights. In the case of the high-pressure engine, Experiment XXVI., when dragging 8 and 9 carriages, the performance was as 26.7 : 30, but the time was proportionably diminished, and from the causes above stated. The pressure in the boiler was the same in each case, but the elasticity of the steam in the cylinder being regulated by the weight upon the piston, the rate of efflux would be thus diminished, and the density when moving slow would, therefore, be proportionably increased. Taking the elasticity of steam in the boiler as constant, and applying this to the area of the piston, the performances will appear different; but, in such cases, the weight of the steam, which is the true measure of

effect, is always proportionate to the work formed.

I shall now give two experiments, made with a view of illustrating this in the loco-motive engines, which may not only be the means of explaining the characteristic properties of those kind of engines, but also of high-pressure engines in general.

EXPERIMENT XXXV.

Loco-motive engine, with two cylinders each 9 inches diameter, boiler 9 feet long, 4 feet 8 inches diameter, density of steam in the boiler 50 lbs. per square inch, length of stroke in the cylinders 2 feet, diameter of travelling-wheels 37 inches, same construction as *Fig.* I. and II. *Plate* V.

Up the plane, Experiment XXVII., the engine dragged 12 loaded carriages, the same as therein described, the distance of 388 yards in 430 seconds.

The resistance by the gravity of the engine and carriages, and the friction of the carriages, as per Experiment XXVII., is 1810 lbs. which was moved over the space of 1164 feet; consequently, $1810 \times 1164 = 2106840$, the effect produced, exclusive of the friction of the engine.

Then $9^2 \times .7854 \times 2 = 127.2$ square inches, the area of the two cylinders, which, multiplied by 50 lbs., the pressure on each square inch is 6367 lbs., the power applied to the pistons. The diameter of the wheels of the engine is 37 inches $= 116.24$ inches cir-

cumference, and as during one double or one complete stroke of the pistons, the wheels make one revolution, the number of strokes will be $\overline{1164 \times 12} \div 116 . 24 = 120$, of $2 \times 2 = 4$ feet each, consequently the piston will have moved through $120 \times 4 = 480$ feet, while the engine moved over 1164 feet. The pressure on the piston is 636 lbs.; the power is, therefore, 636 lbs. moved 480 feet, = 3053280 the power expended.

$$\text{Therefore} \begin{cases} 3053280 & \text{power,} \\ 2106840 & \text{effect.} \end{cases}$$

Whence we find the effective performance equal to 70 per cent. of the pressure of the steam, (of the density in the boiler,) upon the piston; and, if we take into account the friction of the engine, we shall have an effect equal to 88 per cent., and with that the piston moving at the rate of 80 feet per minute.

EXPERIMENT XXXVI.

Same engine, and every other circumstance the same as in last experiment, except the load. The engine was taken down the plane, and 5 of the carriages used in the last experiment attached; the time of drawing them up was 175 seconds.

The pressure of steam and the space passed over being the same as the preceding experiment, we have 3053280, the power expended.

The resistance will be G = 16800 lbs., (the weight of the engine) + 3360 lbs. (the weight of the convoy-carriage) $+ 9408 \times 5 =$ 47040 lbs. (the weight of the carriages) $= 67200 \times \frac{134}{13968} =$

645 lbs. the gravity of the whole train. And $43 \times 5 = 215$ lbs. the friction of the carriages; then $\overline{645 + 215} + \left(\frac{W\,S}{r\,t^2}\right) = 158 =$ 1018 lbs., the resistance, which, in the experiment, was moved through 1164 feet; whence $860 \times 1164 = 1001040$, the effect produced.

$$\text{Therefore} \begin{cases} 3053280 \text{ power,} \\ 1001040 \text{ effect.} \end{cases}$$

Whence we have the effective power equal to 33.3 per cent. of the pressure of the steam upon the piston, when the velocity of the piston is 165 feet in a minute.

The above will shew how vague an idea we have of the performance of a high-pressure engine, by expressing it in terms of horses' power, calculated by applying to the area of the piston the pressure of the steam in the boiler.

The first of these experiments gives 70 per cent. effective power, and the other 33.3 per cent., while in each the elasticity of the steam in the boiler remained the same. The true measure is the quantity, or rather the weight, of steam expended. The weight of steam is, of course, as its density, indicated by the weight on the valve confining it; and the latter, in the two experiments, will be proportionate to the respective intensities of the load; the effect of the first is 1810 lbs. moved over 1164 feet in

430 seconds, and the other 860 moved over the same space in 175 seconds.

Then, $\frac{1810 \times 1164}{430} = 4911$, and $\frac{860 \times 1164}{175} = 5720$,

so that the relative performance, with respect to time and effect, is as 4911 : 5720; which, considering the variation that a trifling diminution of the supply of steam in the former, which was so heavy loaded, might produce, the anomaly is by no means great; and if we take into the account the increase of friction in all the working parts by the intensity of the load, which, in the former, was considerably greater than the latter, the two performances would perhaps be nearly equal.

My object in making these experiments was, to ascertain if any defect of principle arose from the particular nature of the application of these kind of engines; and, whether their effective performance reached as high a maximum as that of similar engines acting in a different manner.—The result will shew, that no such defect occurs; and that, if not a greater, at least as great an effect can be produced upon the load by the steam with these engines as with any other. And that no "loss of power," if one may apply a technical expression, is occasioned in the application of engines to move with the

load, more than what takes place in ordinary engines of the same kind, except what arises from the causes hereinbefore explained.

The quantity of water used, as will be seen by the Tables VI. and VII. varies a little; the average will give about one gallon of water for every 3 lbs. of coal.

As before stated, the true measure of effect is the quantity of work performed with a certain weight of steam. Now, the weight of steam will be proportionate to the quantity of coals consumed, in all cases, unless some cause operate in the interior arrangement of the engines, to produce an alteration in the law. The centrifugal force, produced by the progressive motion of the engine, may, at sudden changes in the velocity, cause a waste of water, by mixing it with the steam, and causing it to pass in that state through the cylinders into the atmosphere. This is frequently found to be the case if the boiler contains more than an ordinary quantity of water, and when the engine is commencing its motion; but still there appears an extraordinary waste of fuel compared with that consumed by the most economical form of high-pressure engines, and it is to this part of the internal construction of the engine that the great defect arises; and that to which the attention of engineers, wishing to

improve the economy of this kind of engines, should be directed.

A great saving will be observed in the construction of the two engines, No. 1 and No. 2, by increasing the dimensions of the tube through the boiler, and thus exposing a greater area of water to the action of the fire. No doubt, a similar increase of saving will be found, by further enlarging the surface of the fire; a circle, however, does not expose the greatest surface in a given area. I have lately put an oval tube into one of the engines upon the Killingworth Rail-road, but not yet having had an opportunity of subjecting it to trial, I cannot at present give the result.

Mr. Watt states, that, in the most judicious furnaces, it requires eight feet of surface of boiler to be exposed to the action of the fire and flame, to boil off a cubic foot of water in an hour. In the Tables VI. and VII. we find the quantity of water used was about 120 gallons an hour; six gallons is nearly equal to a cubic foot, which will make the evaporation about twenty cubic feet of water in an hour; and, by Mr. Watt's rule, the extent of the surface should be 160 feet; if the tube was two feet diameter and nine feet long, the whole surface would not be more than fifty-four feet,

which is considerably below the proper extent, and will account for the great waste of coals.

I shall now attempt to shew the performance of the loco-motive engines, with respect to the conveyance of goods upon Rail-roads, and shall confine myself to their application upon the edge-rail. Taking Experiment XXXIII. as the datum, which, as it was performed in the presence of several eminent engineers, and with a view of ascertaining their performance with respect to the rate at which they can travel in their present state, will be a proper measure of their utility.

The engine, in that experiment, was subjected to a load of 975 cwt., exclusive of the weight of the engine and convoy-carriage; on a mean of the whole number of journeys, the average rate was 6.6 miles an hour. I shall call it 6 miles an hour, for the sake of even numbers. The load was 975 cwt., but, as in the case of carriages moved along Rail-roads, by self-acting planes, we found that the relative resistance in the most favorable and the most unfavorable weather was as 4 : 3, we ought, perhaps, to apply the same rule to the performance of the loco-motive engine. In the case of horses we also found, that in five months

out of the whole year their performance was only $\frac{3}{4}$ths of what it was the remaining seven months. Adopting this to the loco-motive engine,

We have as 4 : 3 :: 975 : 731¼, the minimum performance in $\frac{5}{12}$ths of the time, and 975 the maximum $\frac{7}{12}$ths, the average would make 874 cwt. or 43 tons 14 cwt.

To procure even numbers, I shall say 40 tons, moved at the rate of 6 miles an hour upon a horizontal Edge-rail-road.

Taking this as a standard of the performance of a loco-motive engine upon a level Edge-rail-road, the following Table will shew its relative effect with horses.

TABLE VIII.

Velocity in miles per hour.	Weight conveyed in cwts.	Distance traversed in miles, being that which a horse performs in a day.	Resistance in lbs. upon an edge-rail-road, reckoning the friction equal to the 200th part of the weight.	Power which a horse exerts upon the load from formula $\frac{224}{v}$	Number of horses required to perform the work.	Weight conveyed in cwts. upon an edge-rail-road, by formula $\frac{400}{v}$	Weight which a loco-motive engine will drag upon an edge-rail-road in cwts.	Ratio of performance of a loco-motive engine and horses, when the speed at which they travel is the same in each.	Time in hours occupied by horses in travelling 20 miles, at the respective velocities.	Distance in miles which a loco-motive engine would travel in the preceding time, going at the rate of 6 m. an hour.	Ratio of distance traversed by loco-motive engines and horses, in the same time.	Number of horses' work which a loco-motive engine would be continually performing in the time-column 10, travelling at the rate of 6 miles an hour, and horses at the respective rates of column 1.
2	800	20	448	112	4	200	800	4 : 1	10	60	3 : 1	12
3	800	20	448	74⅔	6	133⅓	800	6 : 1	6⅔	40	2 : 1	12
4	800	20	448	56	8	100	800	8 : 1	5	30	1½ : 1	12
5	800	20	448	44⅘	10	80	800	10 : 1	4	24	1³ : 1	12
6	800	20	448	37⅓	12	66⅔	800	12 : 1	3⅓	20	1 : 1	12

The above Table will shew, in a very striking point of view, the rapid increase in the ratio of performance of loco-motive engines, whose power at all rates of speed is kept the same, over horses, the energy of whose power diminishes very rapidly at increased rates of speed; and this result is not confined to this particular case alone, but applies equally to every other species of art, where animal and mechanical action are brought into competition. The action of horses being limited, must ever curb and check the advance of any art where, from necessity, they are obliged to be employed; but, in the application of mechanical power, there is

scarcely any limit, as our numerous manufactories evince the difficulty of conceiving to what extent it may be carried. The result in the Table may be brought into very familiar comparison with the performance of horses in the stage-coaches upon the turnpike-roads. The difference of resistance between carriages moved upon the common roads, and upon a Rail-way, is from observation found to be about as 7.5 : 1; a horse will, therefore, draw ten tons upon a Rail-way with the same ease that he can draw 27 cwt. upon the common roads, travelling at the rate of two or two and a half miles an hour. The resistance, or the energy of the power which the horse exerts in both cases, will therefore be the same, and be equal to 112lbs.

Let that pace be quickened to 6 miles an hour, and by the Table we should have for the energy of his power 37½ lbs., and in the case of the stage-coaches with 4 horses, 37½ × 4 = 150 lbs. nearly, as the united effort of the 4 horses. Then, as 112 lbs. : 150 lbs. :: 27 cwt. : 36 cwt., the load, which, according to the Table, we should have as the performance of 4 horses upon the common roads, conveyed 20 miles a day. We may now apply this to the loco-motive engine; suppose the stage 20 miles, and that this is the distance which 4 horses will daily convey a stage-coach, weighing 36 cwt. upon the common road, or 36 × 7.5 = 270 cwt., travelling at the rate of 6 miles an hour upon a

Rail-road: a loco-motive engine we have found travels at this rate with 800 cwt.; therefore, if 270 cwt. required four horses, 800 cwt. will require twelve horses, so that we find the united effort of twelve horses continually required to perform the work of one loco-motive engine, both travelling at the same rate of speed, and that speed six miles an hour.

Suppose the quantity conveyed amount to forty tons, four horses travelling at the rate of two miles an hour will, in ten hours, convey this weight twenty miles; if a loco-motive engine be employed, and travelling at the same speed, it will in the same time perform a similar quantity of work, which will be that of four horses; but, supposing that instead of the loco-motive engine travelling two miles an hour, that it averages a velocity of four miles per hour, then in ten hours it will travel forty miles, and convey forty tons that distance, which is equal to the performance of eight ~~hours~~ horses, travelling at the rate of two miles an hour. And again, by further increasing the velocity of the loco-motive engine, until it accomplishes a rate of six miles an hour; then, in ten hours, it will travel sixty miles, and convey forty tons that distance, which would require the united effort of twelve horses.

It is, however, only on long stages where

the velocity of the engine can be made to average six miles an hour, that its performance will reach this maximum effect; the minimum effect being that when their velocity is reduced to the lowest in the Table. It is rather against these engines that they have hitherto been used on stages not exceeding more than four or five miles, where, from the nature of their employment, and the unavoidable stops of short stages, their initial velocity has been reduced to nearly that of horses;—as yet, 3-feet wheels are almost the largest that have been used, furnishing a speed of from four to five miles an hour, which, from the above causes, has been reduced to little more than an average of two or three miles; and their performance, in comparison with horses, has been correspondingly diminished, and, except in few instances, have not exceeded that represented in column six; still even with the speed that the wheels on which they have hitherto been placed permit them to accomplish, their performance has been by no means despicable. Upon a Rail-road, near Newcastle, a loco-motive engine in fifty-four weeks conveyed 53.823 carriages of coals, each weighing 9438 lbs., 2541 yards, and returned with the same number of empty carriages, each weighing 3472 lbs. This was in

fifty-four successive weeks, and, in that time, exclusive of Sundays, the engine, from want of goods to convey, was at least twenty days off work; so that, in 304 days, the performance was 446.815 tons conveyed one mile, or 1470 tons one mile each day; on a stage, only 2541 yards. This engine had 3-feet wheels, which were calculated for a rate of about four miles and a half an hour; with larger wheels, and where the distance to be traversed is greater, the difference of effective speed between horses and loco-motive engines, will be correspondingly increased. In the worst cases, therefore, the relative performances, when the speed is the same as that of horses, will be represented by column 6, and, when the distance and nature of the work is such, that these engines can accomplish an average rate of speed equal to six miles an hour, then the relative performances in the time-column 10, will be represented by column 13, when they will attain their maximum effect. The range of their utility will therefore lay between those two results, and, as the distance and nature of the work permit them to approximate towards either of them, their utility will assume the one character or the other. The least performance of a loco-

motive engine will be equal to that of four horses; when therefore the expence amounts to that of four horses, the comparative utility will be the same. Their cost will, of course, depend much upon the situation of the district in which they are used, with respect to the price of fuel, and other circumstances; and their performance again upon the length and feature of the Rail-road on which they are made to travel: as a sort of approximation, it may be stated, that the average cost will, in many cases, amount to that of three horses, so that, under the most disadvantageous circumstances, when the initial velocity is reduced to an average of two miles an hour, the relative performances with respect to horses will be as 4:3; and when the nature of the road will admit of an average speed of three, four, five, or six miles an hour, then the relative performances will be respectively as six, eight, ten, and twelve to three, as shown in column 9 of Table VIII.; and this, it must be understood, will take place when horses are made to travel at that rate of speed when their performance is the greatest, viz. at two miles an hour; — if they were to be brought into comparison with loco-motive engines when they are travelling at an increased rate of speed, say four miles an

hour, then the energy of their power, in travelling the same distance, is diminished one half, as shewn in the Table, where 100 cwt. is the load with which they can travel at the rate of four miles an hour. We see, therefore, that the value of loco-motive engines depend solely on the speed which they accomplish in travelling; and this, as before seen, will be regulated by the length of stage, and the nature of the road on which they are applied. The most extravagant ideas are at present entertained of their value, and the velocity with which they may be made to travel; something of this took place also at their first introduction, and they were hence employed upon Rail-roads, the most improper for their action; and it is not on that account wonderful that they should, in some instances, disappoint the expectations of their sanguine supporters. I have given experiments to shew, that they are capable, in their present shape, with 4-feet wheels, of accomplishing a rate of six miles an hour. It need scarcely be urged, that if they can travel at that velocity, they can also be made to travel at a less rate of speed; the cost will perhaps be less; smaller engines might be employed, and the consumption of fuel will be diminished; still their

relative performance, with respect to work, will be the same.

Yet, however obvious it may be, that, at a less rate of speed, the engines can travel with the same load, it will not perhaps be equally obvious, that at a greater rate these engines will also travel with that load; and, to bring it to the apprehension of the reader, will require a little explanation.

We have before seen that the pressure upon the piston depended upon the density of the steam in the boiler, and the velocity of efflux to the cylinder, regulated by the area of the aperture through which it issues: and experiment shewed, that when the piston was moving at a less rate, that the steam acted with a greater force upon it, when the density in the boiler was the same. We will suppose, then, that it requires a certain number of cylinders full of such a density to propel the engine with 4-feet wheels one mile, and that the boiler is capable of furnishing 90 cylinders full, viz.

45 double strokes in a minute; now, as in each double stroke the wheel makes one revolution, then it will make 45 revolutions in a minute, and the progressive motion of the engine is $4 \times 3.1416 = 12.5$ feet in a revolution, or 12.5

$\times 45 = 562.5$ feet in a minute, and $562.5 \times 60 = 33750$ feet an hour $= 6.4$ miles, or nearly.

And the resistance or load is 384 lbs. (the friction of the engine) $+ \overline{(40 \text{ tons} \times 2240} \div 200) = 448$ lbs. (the friction of the load) $= 832$ lbs., moved in one revolution of the wheel 12.5 feet, $= 10400$, the resistance: and the power is $9^2 \times .7854 \times 2 = 127.2$ area of the pistons, which multiplied by 50 lbs., the pressure of the steam in the boiler, we have $127.2 \times 50 = 6361.7$, which, in one revolutionof the wheels, is moved 4 feet, $= 25446$, the power.

Whence $\left\{ \begin{array}{l} 25446 \text{ power,} \\ 10400 \text{ resistance,} \end{array} \right\}$ equal to 40.8 per cent.

If now the wheels be increased to 5 feet, then in each revolution the space described will be $5 \times 3.1416 = 15.7 \times 45$ revolutions $= 706.5 \times 60 = 42390$ feet, or 8 miles an hour.

But the resistance, in this case, will be different; while the engine is making one complete stroke, the space moved over with 4-feet wheels is 12.5 feet; and, during the same stroke, with 5-feet wheels, 15.7 feet.

Now we have before seen that, in one complete stroke of the engine, the same quantity of friction took place, (except that which arose from the action of the wheels upon the rail) whether the engine moves over 12.5 or 15.7 feet, the same extent of attrition occurring from the various working parts of the engine. The retardation of friction will then be inversely as the spaces passed over, viz.

As 12.5 : 15.7, or as the diameter of the wheels.

The total friction of the engine, with 4-feet wheels, we before found to be 384 lbs. Then, as 5 : 4 :: 384 : 308 lbs. the friction of the engine with 5-feet wheels. Supposing the same load taken, the resistance will now be 308 + 448 = 756 lbs., moved over in one revolution of the wheel, or in 15.7 feet, = 11869, the resistance; and, if the density of steam in the boiler be the same, the power will, also, remain as before.

Whence $\left\{\begin{array}{l}\text{25446 power,} \\ \text{11869 resistance,}\end{array}\right\}$ equal to 46.8 per cent.

The relative resistances, at 6 and 8 miles an hour, will therefore be as 10400 : 11869, or as 34 : 39.

By reducing the load equivalent to that amount of resistance, or from 40 to 35 tons, the engine would then travel at the rate of 8 miles an hour with the same expenditure of steam as at 6 miles an hour; but, as the effect will invariably be greatest when the load bears as great a proportion to the friction of the engine as possible, it will always be advisable to make the load approach the nearest to that which the engine can overcome by the adhesion of its wheels upon the rails. If, therefore, instead of diminishing the load, we produce an additional quantity of steam by increasing the surface of the fire, or, in fact, the size of the tube, we can, either by enlarging the aperture through which the steam issues to the cylinder, or by increasing the area

of the piston, travel with the same load at 8 miles as at 6 miles an hour; the only power wanted being an additional quantity of steam, in the proportion of 39:34 above what was required for a rate of 6 miles an hour.

In the application of the loco-motive engine to convey goods upon Rail-roads, the effect will always be a maximum when the load is the greatest that the adhesion of the wheels will permit. The latter will, therefore, be the utmost limit of their application, and will be the rule for the inclination of road on which they can be made to travel: still they should be kept considerably within this limit, or that to which their adhesion will enable them to effect their own progressive motion, as their utility will depend upon the dragging a load after them; and when this is small, compared with their own weight, then their effective performance will be reduced below a profitable standard, and other means should then be resorted to.

It will scarcely be necessary to give a table on the weight of goods which a loco-motive engine can take along a Rail-road with different inclinations, as, when occasional inequalities occur, the nature of their power will enable them to exert considerably greater

force than the standard I have assigned them; and by moving slower, until they traverse the ascent, they can again resume their usual speed, after they have surmounted it. We have already seen an increase of effect from 33 to 70 per cent. by a diminution of speed, which shews that there is a sufficiency of inherent power in the engines, to enable them to traverse occasional undulations that may present a transient increase of resistance: and this may render the use of a table, which could only shew the performance, at a determinate and unvarying angle of inclination, unnecessary; still it will, in general, be found most advantageous to preserve as strictly as possible, a uniform inclination of road, suitable for the nature of the traffic, and the relative weight of goods to be conveyed in both directions.

In the use of loco-motive, as with every other kind of engines, where steam is the moving power, we need never diminish the quantity of work to be performed, as we can always effect the performance, by an augmentation in the power of the engine. In the use of horses we are restricted—they can only be made to produce a certain effect; and their action must, therefore, be limited: we have seen them superseded in every other species of

mechanical action, and the same law extends to their application upon Rail-roads.

After the observations I have previously made, respecting the use of loco-motive engines, and the principles of their construction, it will be scarcely necessary for me to say, that I deem them worthy of attention; and that I think they will ultimately be made generally useful, and be extended, on suitable lines of road, in preference to horses, in the conveyance of goods along Rail-roads: I must, however, beg leave to state, that I am far from believing they are at present arrived at any way near to a state of perfection; on the contrary, I think them far from perfect: the most ridiculous ideas have been formed, and circulated, of their powers; and though I am of opinion, when made the subject of attention amongst engineers, they will advance in improvement like other machines, they must as yet be considered only in their infancy, and as not having reached beyond the trammels of prejudice. It is far from my wish to promulgate to the world that the ridiculous expectations, or rather professions, of the enthusiastic speculist will be realised, and that we shall see them travelling at the rate of 12, 16, 18, or 20 miles an hour: nothing could do more harm towards their adoption, or general improvement, than

the promulgation of such nonsense. I recommend the use of them in proper situations, because, after a daily opportunity of witnessing their performance for near eleven years, I think the principle of their action is founded on good grounds; and that they will, ultimately, reach such a state of perfection, that, by facilitating the conveyance of goods, at a rate of motion far beyond the power of horses on canals, they will be of infinite advantage to commerce. Their progressive motion is effected with little or no injury to the road: the surface of the rails is the only part subjected to their action; and these are so durable, that their wheels has scarcely any effect upon them; and their action may thus almost be said not to affect, or at all injure, the road whereon they travel: with horses it is different; the action of their feet alone form a species of expenditure by no means trifling, and which is unknown in the use of loco-motive engines.

We are not to look at these engines in their present shape and construction, and apply them to purposes, and upon Rail-roads, for which, by their action, they are never intended; they have hitherto been used only where fuel is no object; where, in fact, economy, in the common acceptation of the

word, consists in its destruction; and if we, therefore, apply them to a district where the cost of fuel is great, we shall find them very deficient in economising that article: the question is, are they capable of such an organization of parts as will effect that, to so great an extent as other engines? I am afraid they perhaps are not, but they certainly are capable of approximating much nearer to it than they are at present; the relative economy is now about as 3:7, and we have seen, in a very trifling alteration of form, a saving in the proportion of 2534:2101; it cannot, therefore, be doubted but a further saving will again be effected, by pursuing the same rule still farther; and that, ultimately the consumption, will be so much reduced, as to approach very near to that of other steam-engines.

There is another great objection urged against them, which is, the noise that the steam makes in escaping into the chimney; this objection is very singular, as it is not the result of any inherent form in the organisation of such engines: but an accidental circumstance. When the engines were first made, the steam escaped into the atmosphere, and made comparatively little noise; it was found difficult then to produce steam in sufficient quantity to keep the engine constantly working; or rather, to obtain an adequate rapidity of current

in the chimney, to give sufficient intensity to the fire. To effect a greater rapidity, or to increase the draught of the chimney, Mr. STEVENSON thought that by causing the steam to escape into the chimney through a pipe with its end turned upwards, the velocity of the current would be accelerated, and such was the effect; but, in remedying one evil, another has been produced, which, though objectionable in some places, was not considered as objectionable on a private Rail-road; the tube through the boiler having been increased, there is now no longer any occasion for the action of the steam to assist the motion of the heated air in the chimney. The steam thrown in this manner into the chimney acts as a trumpet, and certainly makes a very disagreeable noise; nothing, however, is more easy to remedy, and the very act of remedying this defect, will also be the means of economising the fuel.

I have before said, that economy of fuel has not been an object where those engines have hitherto been used; no attempt has, therefore, been made to lessen it; and the steam, after performing its effect in the cylinders, has been allowed to escape into the atmosphere. The water with which the engine is supplied, has generally been heated in a vessel by the side of the road, and carried in a barrel, from which

it is pumped into the boiler as occasion requires. In the detail of the Experiments I have not noticed the fuel required to heat the water, as I considered, that where economy of fuel was an object, the water would be heated by other means, either by throwing the steam escaping from the cylinder amongst the water, or by husbanding some of the radiation, which takes place unnecessarily on so many parts of the machine. Nothing is wanted to destroy the noise, than to cause the steam to expand itself into a reservoir, and then allow it to escape gradually to the atmosphere through the chimney. Upon the Wylam Rail-road the noise was made the object of complaint by a neighbouring gentleman, and they adopted this mode, which had the effect above-mentioned. S, *Fig*. I. *Plate* VI. of that engine, will shew the reservoir into which the steam is allowed to enter, after it leaves the cylinder C; the steam there expands itself, and then issues through the pipe *r'*, into the chimney, without that noise made by the others. Innumerable methods of preventing the noise and heating the water might be suggested; one pipe within another, placed around the frame on which the boiler rests, the interior one containing the water, and the steam being made to pass from one end to the other within the outer one, and in contact with the exterior

surface of the inner pipe, would both destroy the noise and heat the water.

The noise from the working parts of the engine is comparatively trifling, and might be almost entirely annihilated by a little care in the construction.

There is another objection urged against these engines, certainly not on account of their application to Rail-roads, but extending to all similar engines, viz. on account of the great elasticity of the steam in the boiler. I need not again repeat, that the elasticity is considerably less in the cylinder. At the first introduction of these engines it was found, as before stated, difficult to keep up a proper degree of elasticity of steam in the boiler; or rather, an adequate supply of steam; and as they had to travel on short stages, the pressure in the boiler was increased to 50 lbs. per square inch, which, in the journey, was allowed to expand, and thus acted as a sort of reservoir. Since they have been improved, a sufficient quantity of steam is capable of being raised at all times; by enlarging the apertures between the boiler and the cylinder, the elasticity of the boiler might be greatly reduced; and the engine might be then made to assume the character of a low-pressure engine.

Having thus given as minute a description of Rail-roads, and the different kinds of motive power employed upon them, as my time and the extent of my researches permit, it may not be uninteresting to give a sort of brief outline of single and double lines of road, with their passings, as they may be required for the general conveyance of goods.

In most of the Rail-roads in the neighbourhood of Newcastle-upon-Tyne, and other districts of Great Britain, which I have visited, one main line of road is laid the whole distance, with short pieces of double road at certain intervals, and proper passings between them, for the carriages going in one direction to pass the others returning in the opposite direction. In public lines, and for general traffic, perhaps, in many cases, double lines of road the whole distance may be preferable: but this will, in all instances, be regulated by the peculiar circumstances of each particular line of road. Dividing them into two kinds, viz. single lines with different kinds of passings, and double lines with common passings from one to the other.

Fig. XII. *Plate* II. will represent a double road, with the crossings from one line to the other, for the carriages to pass each

other: A A′ is one line, which may be for the carriages going in either direction, say from A to A′ and B B, the other line for the carriages traversing the opposite direction, say from B′ to B; those two lines are supposed to extend the whole distance traversed, from one end to the other. When the goods to be conveyed are to travel at the same rates of speed, perhaps few, if any, passings will be required from one road to the other; but, when it is intended for the conveyance of passengers also, or for the transit of light goods at a swifter pace, then it will be necessary to have certain passings, so that the carriages moving faster can cross to the other road, and pass those moving slower; when they can again come upon their own road, and so proceed. Thus, suppose a train of heavy goods travelling along the road A towards A′, and another train of lighter goods or passengers coming in the same direction, the heavy train can then pass along the crossing *a b* into the road B B′, when the lighter train will pass, and the heavy one will again resume its former track, by proceeding along the crossing *c d*. In like manner, a light train of carriages proceeding along the road B′ B towards B, encounters a heavy train travelling

in the same direction; by the proper signal, the heavy train passes along *fe* into the road A′ A, until the other train passes it, when it again gets upon its former track, by passing along *de*. In this manner, when the road is pretty straight (which in public lines should always be the case) the carriages will never be interrupted by each other: as, if engines are used, the weights they take being large, there will not be a great number upon the road at once, and the heavy ones making a point of giving way to those proceeding at a swifter rate, always keep clear of those travelling with passengers and light goods.

The mode of causing the carriages to cross from one road to the other, is effected in the same manner as formerly described with the self-acting and engine-planes. A moveable rail, similar to A A′, *Fig.* X., is placed at the junction of the passing with the main line of road; when this moveable rail is thrown back in the position shewn in the drawing, the carriages proceed along the main line without interruption; but when put close to the other rail, as shown by the dotted line in the drawing, this rail, acting against the projecting ledge on the wheels of the carriages, prevents them from continuing along the main line, and diverts

them into the passing; the rail on the opposite side having an opening for the ledge to pass along, as shewn in the rail *Fig*. XI.

Fig. IX. shews the sort of rail laid at the point when the four rails meet together, *a* being the point where two of the rails meet, and *b c* when they branch into two separate rails again; the upright ledges *d d* and *e e* standing up about $\frac{3}{4}$ inch, prevent the wheels from running off the road at the junction of the rails, where the projecting ledge on the wheels has no effect in keeping them upon the road. By attentive examination of these rails, on the larger scale, *Figs*. IX. X. and XI. and applying them to the lines of road shewn in a smaller scale in *Fig*. XII. it will be seen in what manner the wheels of the carriages are directed into the proper road. The moveable, or switch rail, is always to be put into the proper position by the attendant of the train of carriages, to divert them into the proper track, otherwise they would always continue along the main line. *Figs*. XIII. and XIV. *Plate* II. will shew two single lines of road, with passings of a different kind; A A′, *Fig*. XIII. is the main line, extended the whole distance, along which the carriages travel, in both directions; B B′ is a siding or passing, for the carriages going in opposite directions to pass each other; this kind of siding is used

when the goods are all conveyed in one direction, where the distances are short, the motion slow, and where, perhaps, the necessity for the carriages passing each other, do not frequently occur. In this form of road the carriages will always continue along the main line of road, unless diverted into the passing by the moveable rail, previously described, the attendant having to put it into the proper position, whenever the carriages are likely to meet each other. Thus, if a train of carriages, coming along the main line, in the direction A A′, are likely to meet another train coming in the opposite direction, then the attendant puts the moveable rail into the proper situation, when the empty train proceeds either along *a* B, or *b* B′, as the case may happen; and the carriages pass each other.

This form of siding is much, or indeed almost invariably, used in all the Rail-ways, where the goods are to be conveyed in one direction only, the empty carriages being the returning load; such as the conveyance of coals from the coal-pits to the shipping places. In these cases, the loaded carriages always keep the main line, and the empty carriages pass into the siding; the moveable rail being placed on that end of the crossing towards which the empty carriages are proceeding. These mo-

veable rails are very inconvenient, requiring the constant precaution of putting them in their proper places, whenever the carriages are to pass each other; it is true, they do not affect the loaded carriage passing on the main line; the projecting ledge of the wheels always displacing them from their position in contact with the rail, into that which allows of the free passage of the carriages without interruption. *Fig*. XIV. *Plate* II. will show a mode of obviating these inconveniences of the moveable rail, by a particular form of laying the road; by which the carriages are enabled to pass each other without the danger of meeting, and where no moveable rail or switch is required. A, will represent the main line proceeding in one direction, and A′ the same line passing in the opposite direction. The carriages having always a tendency to continue moving in a straight line, will, in passing along from A towards *d*, keep the road A *d c*; and, in like manner, the carriages proceeding in the opposite direction A′ *a*, will keep the road A′ *a b*; the two trains will thus proceed into different roads, and, passing each other, will join the main line again, the former by the road *c a*, and the latter by the road *b d*.

This form of passing will be very useful upon public lines; whereas any neglect of placing

the moveable switch in the proper place might occasion many inconveniences.

These kinds of passings will be the same for the loco-motive engines as for the common carriages, drawn by horses; no alteration of the road being required for the former, which, in public lines of road, where the general convenience requires that it should be equally adapted to every species of motive power, is a great desideratum.

CHAPTER IX.

COMPARATIVE PERFORMANCES OF MOTIVE POWER ON CANALS AND RAIL-ROADS.

The existing agitation of the public mind, respecting the relative utility of Rail-roads and canals, in the transit of goods from one place to another, renders it a subject of proper enquiry to ascertain the relative performances of the different kinds of motive power upon those two species of internal communication.

I shall, therefore, give a brief comparison, founded on the foregoing deductions of the different kinds of motive power upon Rail-roads, with the performance of horses by the present mode of canal navigation.

Not having had an opportunity, from my own personal observations, of ascertaining, with

sufficient accuracy, the weights which a horse will drag in a boat upon a canal, I shall be obliged to have recourse to the reports of those engineers whose practice in that line has enabled them to obtain the necessary data.

Mr. R. Stevenson, of Edinburgh, in his report on the Edinburgh Rail-way, in 1818, states, " Upon the canals in England, a boat of 30 tons burden is generally tracked by one horse, and navigated by two men and a boy; on a level Rail-way it may be concluded that a good horse, managed by a man or lad, will work with eight tons; at this rate, the work performed on a Rail-way by one man and a horse is more than in proportion of one-third of the work done upon the canal by three persons and a horse;" and Mr. Stevenson, in his calculations afterwards, assumes the power of a horse, upon a good Rail-way, equal to 10 tons.

Mr. Sylvester, in his report on the Liverpool and Manchester Rail-way, gives 20 tons as the performance of a horse upon a canal, travelling at the rate of two miles an hour.

The variation between these two statements may have arisen from the observations being made on canals of different widths. Mr. Stevenson, in another report, states, that the striking difference between the draught of horses, on coming out of a narrow canal, into a

more capacious one, induced the reporter to give the subject particular attention; and, by means of experiments made with the dynamometer, so far as he had an opportunity of carrying the experiments into effect, the difference appeared to be at least one-fifth in favor of the great canal.

Under these circumstances, I shall take the performance of a horse equal to that of 30 tons upon a canal, which is the greatest I have seen assigned by any one, and we have previously found the energy of his power equal to 10 tons upon a Rail-way; which will make the relative performances as 3 : 1.

I am not acquainted with any experiments, made on a practical scale, to ascertain the ratio of the increase of resistance, either with different weights, or with the same load moved at different velocities, upon a canal; but it is assumed, by all writers on the subject, as a law of hydrodynamics, which appears unquestionable, that the resistance at least is proportionate to the square of the velocity.

Taking these premises as sufficiently established, the Diagram III. (*page* 183) will represent the resistances at different velocities: and the following Table will shew the relative quantity of work performed by horses dragging boats on canals, and carriages upon Rail-roads.

TABLE IX.

Velocity in miles per hour.	Weight conveyed in cwts.	Distance in miles, being that which a horse travels in a day.	Resistance upon a canal in lbs., taking a horse's power at 112lbs., and supposing this force will drag a boat of 30 tons, at 2 miles an hour.	Resistance upon a rail-road in lbs., as per Table VIII.	Power which a horse can exert upon the load, at the respective velocities, from formula $\frac{224}{v}$	Number of horses required to perform the work upon a canal.	Number of horses required to perform the work upon a rail-way.	Ratio of the performance of horses, with respect to work on canals and rail-roads.
2	800	20	150	448	112	1.3	4	4 : 1.3
3	800	20	337	448	74⅔	4.5	6	6 : 4.5
4	800	20	600	448	56	10.7	8	18 : 10.7
5	800	20	937	448	44⅘	21.2	10	10 : 21.2
6	800	20	1350	448	37⅓	36.	12	12 : 36.

From this we find, that, when the rate of speed is about two miles an hour, the quantity of goods which a horse will convey upon a canal, is three times that which the same horse can convey upon a Rail-road. And that, when the velocity on each is about $3\frac{1}{2}$ miles an hour, the resistance of the canal increasing as the square of the velocity while that on a Rail-road remaining the same, the two become equal; and a horse is then enabled to drag as much weight upon a carriage on a Rail-road, as in a boat on a canal. When the velocity is further augmented, then the disproportion becomes

greater, and a much heavier load can be conveyed on a Rail-road, with the same intensity of motive power, than can be done on a canal.

If, therefore, the rate of tonnage on a canal, arising from the cost of forming and keeping in a state of active use, together with the cost of boats, be not greater than the tonnage required to form and keep a Rail-road in repair, and also the carriages by which the goods are conveyed ; then the relative economy at different rates of speed, in the transit of goods upon canals and Rail-roads, will be represented by column 9 of the preceding Table. But as, in general, the formation of a canal costs about three times as much as the formation of a Rail-way, and the annual charges of keeping the boats, towing-paths and bridges, &c. in repair, is also considerable, if those expences be as much greater with a canal than upon a Rail-road, so that they will compensate for the extra advantage of the canal in the greater quantity of goods conveyed at a slow rate, then their relative utility will assume a different appearance, and the Rail-way, as requiring a less investment of capital, and less annual charges, may be superior even at the lowest and most advantageous rate of motion upon canals; and, where facility or expedition

is an object, then at the more rapid rates of speed the Rail-way will be proportionably superior.

These, however, being matters of calculation, where every instance may present a different conclusion, and depending upon all the various concomitant circumstances incident to each particular case, cannot, in a work like this, be made the subject of even conjecture, I have endeavoured to furnish all those data which appeared general, and which applied to the two modes in conjunction with each other, in a practical and general point of view. It must be left to those acquainted with all the circumstances of each particular case, when they come into competition with each other, to judge, from the individual situations, which of the two is preferable.

When it becomes a subject of discussion, which of the two modes are to be adopted, it assumes rather a different shape than when a Rail-road is to enter into competition with a canal already formed. In the latter case, the canal proprietor commences with considerable advantage by the additional quantity of goods which a horse can drag at a slow pace upon a canal, where perhaps a little loss of time may be no object; the canal proprietor may, even with his great investment of capital, by reducing

his rates of tonnage extremely low, be enabled to compete successfully with a Rail-way.

For although a horse may, when travelling at the rate of four or six miles an hour, convey a greater quantity of goods upon a Rail-way than when employed in dragging goods at the same velocity upon a canal; yet still a horse cannot drag more goods at the rate of four miles an hour upon a Rail-way, than he can at two miles an hour upon a canal; for in no case does the greatest quantity of work that a horse can do, at the most beneficial pace on a canal, reach below three times that which a horse can do at any pace upon a Rail-road.

For the conveyance of passengers, or where the transit of any species of goods may require a celerity of four miles an hour, then Rail-ways become unquestionably more economical than canals; but if the question be the abstract performance, or quantity of goods to be transported from one place to another without reference to speed; then the canal will at all times have a superiority over Rail-roads, in point of *quantity of work* done by a horse, in the proportion of 3 : 1. The comparative expence arising from the extra interest of capital, and the annual charges and maintenance of a canal may reduce this proportionate performance near to an equality;—or, if the one compensate fo the other, then perhaps the less

well known, as also the laws by which they are governed in falling down inclined planes.

The force with which a body is accelerated down an inclined plane is to the whole gravitating force of the body falling freely, as the height of the plane to its length.

Let H = the height of the plane,
L = its length,
W = the weight of the descending body,

Then the gravitating force of the body down the plane, which may be expressed by G, will be

$$G = \frac{W\,H}{L} \quad (1)$$

If we make $r = 16\tfrac{1}{12}$ feet, the space which a body will describe in a second of time, by falling freely, and t = the time in seconds,

Then the space S, which a body will describe upon any inclined plane, in falling t seconds will be

$$S = \frac{G}{W} \times rt^2 \quad (2)$$

For instance, if the height of the plane be equal to the 36th part of its length, or the descent be one inch in a yard —then, by (th. 1) the force by which the body is urged down the plane will be equal to the 36th part of its weight; and (th. 2) the space which it will describe in the first second of time, will be the 36th part of $16\tfrac{1}{12}$ feet, or $5\tfrac{13}{36}$ inches; and, by the laws of falling bodies, the spaces passed over being as the square of the times, the space described, at the end of any other time, will be equal to the square of that time multiplied by $5\tfrac{13}{36}$ inches.

This will be true when the body descending the plane is without friction; but as no carriage can move without rubbing parts, and, consequently, liable to friction; we must make allowanee for this, otherwise the result in practice will not accord with the theorem.

The friction of carriages, moved along Rail-roads, will be afterwards shewn not to differ materially from that of uniform resistance; we may, therefore, express the resistance opposed by friction to the body moving freely down the plane by F, and consider the diminution of the gravitating force of the body, by this cause, equal to the amount of the friction; hence, retaining the former symbols,

$$\text{we have } S = \frac{G - F}{W} \times rt^2 \text{ (A)}$$

$$\text{and } F = G - \frac{W\,S}{rt^2} \qquad \text{(B)}$$

We can, therefore, determine the friction F of any carriage or waggon by the latter formula, in causing them to descend a certain known declivity; and, ascertaining the space passed over in a given time, the difference between the space actually passed over, and that which the body ought to have described in descending freely, will be the diminution by the effect of friction, and will be a correct estimate of its amount.

Thus, find the gravitating force of the body down the plane, by multiplying the weight of the body by the height of the plane, and dividing the sum by the length; then multiply the weight of the body by the space passed over, and divide this sum by the square of the time in seconds, multiplied by $16\frac{1}{12}$ feet, and subtract this quotient from the gravitating force of the body, and it will give the friction.

This comprehends a body, or system of

the ascent of a train of carriages by the descent of a similar train more heavily loaded in a given time. The respective weights W and w of the descending and ascending train of carriages being given, we shall then have the following known quantities derived from the preceding experiments, viz. F and f, by Table I. p. 194, φ by Table II. p. 214.

Then, taking the friction and resistance of the several moving parts as deduced, by the foregoing experiments, and making T = the required time of descent of the carriages down the plane $= \frac{4}{3} t$, we have

$$T = \frac{4}{3} \sqrt{\frac{(W + w)\,S}{(G - F')\,r}}$$

whence the preponderance of gravity necessary to effect the descent, in all states of the weather, in the time T, will be

$$G - F' = \frac{(W + w)\,S}{9.04\,T^2}$$

and, having the weight of the descending and ascending trains of carriages, the inclination of the plane will be

$$\frac{H}{L} = \frac{\frac{(W + w)\,S}{9.04\,T^2} + \varphi + F + f}{W - w}$$

In the caes of a single train of carriages dragging a rope after them, we have

$$G - F' = \frac{W\,S}{9.04\,T^2}$$

This expression of G, which represents the gravitating force of the carriages, will, also, represent the action of any other power; and will shew the force required to urge the body, or train of carriages forward, whether they have to descend or ascend planes inclined to the horizon, or upon level planes.

In practice, therefore, we must either elevate the plane, or increase the number of carriages,

until we obtain the requisite preponderance; but, in every case, it will be necessary, in order to secure the constant action in winter and summer, that the excess amount to that given by the above formula.

Before dismissing the subject of self-acting planes, it may be necessary to state, that considerable regard should be observed in forming the line into a proper descent, or into that in which the velocity of the carriages, on all parts of it, shall be nearly equable as possible.

The action of gravity causing bodies to descend with velocities uniformly accelerated, the motion of the carriages upon a plane with a uniform descent will be very variable; being accelerated, as the square of the times employed in traversing the plane. The plane should not, therefore, be made with a regular and uniform descent; but such as will give a greater preponderance of gravity at the commencement, and then diminish in such a ratio that the diminution of preponderance will abstract as much gravitating force as will compensate for the increasing velocity of the carriages, so that the two will counteract each other, and thus produce a comparatively uniform velocity in the carriages on the plane. The line of descent to perform these conditions is rather difficult to determine, but perhaps will approach near to the curve called a cycloid.

investment of capital in a Rail-road, and the greater certainty of transit, may make it superior to a canal; but, unless the disparity of cost is great between a Rail-road entering into competition with an existing canal, or unless some extraordinary circumstances in the nature of the traffic occur, it may be difficult to say, when horses are the motive power on each, which is superior.

There is one very important property in a Rail-way, which gives it great advantage over a canal, viz. the range of undulation which its nature permits; a straighter and shorter line can mostly be made between one place and another, which, from the necessity of having canals always perfectly level, or at least that level only broken at certain intervals by the occurrence of locks, occasions frequently a difference in distance of considerable magnitude, and this may diminish the comparative cost of transporting goods, and give a superiority to Rail-roads.

And again, in many cases, where the principal part of the goods are to be conveyed in one direction by a proper inclination of the Railway, the weight of goods may, in some instances, be considerably augmented without presenting a greater average-resistance than previously stated, when the relative perform-

ance upon Rail-roads will be proportionably increased.

Having thus given a few hasty remarks on the comparison of Rail-roads with Canals in the use of animal power, I shall also give a brief comparison between the use of mechanical power on Rail-roads, and animal power on canals; and here, as in every other case, where the two species of action come into competition, we shall find the mechanical power outstrip the animal in general economy.

Table of the relative performances of horses dragging boats on canals; and loco-motive engines, dragging carriages upon Rail-roads. The former supposed to be without locks, and the latter horizontal.

TABLE X.

Velocity in miles per hour.	Weight conveyed in cwts.	Distance in miles, being that which a horse travels in a day.	Number of horses required to perform the work upon a canal, from Table IX.	Time in hours occupied by horses in travelling 20 miles, at the respective velocities of column 1.	Distance in miles which a loco-motive engine would travel in that time, upon a rail-road, going at the rate of 6 miles an hour.	Rates of distance traversed in the same time by loco-motive engines upon a rail-road, and horses dragging boats in a canal.	Number of horses' work which a loco-motive engine will perform, travelling at the rate of 6 miles an hour, in the time-column 5.	Ratio of the performance of horses on canals, and loco-motive engines on rail-roads, in the time-column 5.
2	800	20	1.66	10	60	3 : 1	4	1 : 4
3	800	20	4.5	$6\frac{2}{3}$	40	2 : 1	9	1 : 9
4	800	20	10.7	5	30	1.5 : 1	16	1 : 16
5	800	20	21.2	4	24	1.2 : 1	24	1 : 24
6	800	20	36.	$3\frac{1}{3}$	20	1 : 1	36	1 : 36

bodies, descending an inclined plane, and opposed only by their own friction and inertia; but the principal use in practice is to employ the preponderance of a descending train to drag up the returning empty carriages. The gravitating force has then to be opposed, (in addition to the friction of the descending train,) to the friction and gravity of the ascending train, and also of the rope or chain by which they are drawn up the plane. The gravitating force of the loaded carriages will then be the sole moving power; and the resisting or retarding force composed severally of the gravity of the ascending carriages, and the friction of the whole train.

If we make F' represent the whole retarding force, opposing the motion of the descending train,

and $w =$ the weight of the ascending train of carriages,

Then, as a body requires the same force to propel it upwards through a given space, which gravity would produce in it by its fall through that space, or the force which a body will acquire by falling through a certain height, will propel it upwards through the same height; consequently, the ascending train of carriages will oppose the motion of the descending train with a force equal to the sum of their friction and gravitating tendency down the plane;

$$\text{and we have } S = \frac{G - F'}{W + w} \times rt^2 \quad (C)$$

$$\text{and} \quad F' = G - \frac{(W + w) \times S}{rt^2} \quad (D)$$

also, $t = \sqrt{\frac{(W+w) \times S}{G - F' \times r}}$ (E)

This expression of F′ is composed of four distinct parts, viz. the friction of the descending train of carriages; the friction of the ascending train; their gravity; and the friction of the rope.

Make $g =$ the gravitating force of the ascending train $= \frac{wH}{L}$

$f =$ their friction $= g - \frac{wS}{rt^2}$

$\phi =$ the friction or resistance of the rope.

Then $F' = F + f + \phi + g$.

And having the friction of the carriages and their gravitating force, the friction of the rope

will be $\phi = F' - (F + f + g)$ (F).

In the application of the inclined plane to practice, it will be requisite, as before stated, that the quantity of work should be done with the least cost; and this will be accomplished when the descent of the plane is such as will perform the work required, without laying unnecessary strain upon the rope employed for the purpose: this can be effected either by employing a commensurate number of carriages upon, or by giving additional elevation to, the plane. Any body, or system of bodies, placed upon a plane inclined to the horizon, will, if the gravitating tendency of the body down the plane exceed its friction, begin to descend, and its motion will be

From this Table, we find that a loco-motive engine, effecting a constant average velocity of six miles an hour, will, in ten hours on a Rail-road, perform the work of four horses employed in dragging goods at the rate of two miles an hour upon a canal; and, as this rate of speed on a canal is that when the performance of a horse is a maximum, we derive the conclusion—*That so long as the expence of one loco-motive engine does not exceed that of four horses, and their attendants; then goods can be conveyed with the same expenditure of motive power at six miles an hour upon a Rail-road, that they can be conveyed at two miles an hour upon a canal.*

I have elsewhere stated that, in general, one loco-motive engine, in certain districts, may be estimated to cost as much as three horses; but the comparison was made with horses upon Rail-roads, where one attendant to each horse is sufficient. On canals it will be different, as the attendants upon each horse and boat are generally three; — the relative cost of loco-motive engines will therefore be diminished, and their utility, in comparison with horses on canals, proportionably increased.

But this is not the only benefit resulting from the application of steam power to Rail-ways, viz. that goods are conveyed with the

same expenditure of motive power on a Rail-road; at the rate of six miles an hour, that goods can be conveyed at the rate of two miles an hour upon a canal. If it be attempted to augment the velocity on a canal to three miles an hour, then one loco-motive engine on a Rail-road will, in six hours and two thirds, perform the work of nine horses on a canal;—and if the velocity be further increased to four miles an hour, then, in five hours, the loco-motive engine will perform the work of sixteen horses; and as often as these times are repeated, a similar ratio of performance will be accomplished.

It follows, from this, that the only superiority existing in any part of the economy of canals, and that wherein a transient advantage over Rail-roads occurs, and which consists in the less resistance opposed to the motive power in transporting heavy goods at a slow pace; is superseded by the application of machinery to Rail-ways. And this result may be expected whenever, as previously stated, the nature of the work permits the application of mechanical power in the one case, and it is brought into competition with animal labour in the other.

These observations of the relative performances, with respect to work on Rail-roads and

Canals, apply to the motive power only. If the formation and annual charge of a canal exceed that of a Rail-road, then a further increase of advantage is produced in favour of Rail-roads;—on the contrary, if the balance is in favour of a canal, then it will become a question, whether the additional celerity in the transit of goods by a Rail-road, will compensate for any additional cost of the Rail-way. In general, the difference of cost, both in the formation and annual charges, is presumed to be in favour of Rail-roads; and, if any judgment can be formed from the tonnage upon the various canals, in the different districts of England, the presumption appears nearly indisputable.

The trifling injury done to the road by the action of the loco-motive engine, considerably enhances its value, by diminishing the charges of tonnage for annual repairs, which, added to the less investment of capital required in the formation of a Rail-road, excites reasonable expectations of a very important change in the economy, and also celerity, of internal communication.

In the above disquisitions, canals have been compared in their most favourable state, as being without locks; any variation from this, will throw the balance more in favour of Rail-roads.

It will not perhaps be necessary, in a work like this, to explain at greater length the relative merits of Canals and Rail-roads; local circumstances may effect general results, but unless other causes transpire than the simple abstract question of the two modes in comparison with each other, we have, by the application of mechanical power to Rail-roads, the advantage of a less investment of capital, and also a saving by the motive power; which produces, in the general economy of internal communication, a degree of importance that, combined with the celerity of dispatch, cannot fail of being of the utmost benefit to commerce.

THE END.

LONDON:
W. LEWIS, FINCH-LANE, CORNHILL.

Fig.I

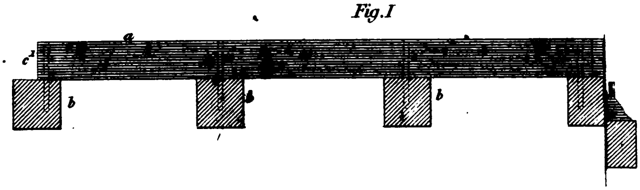
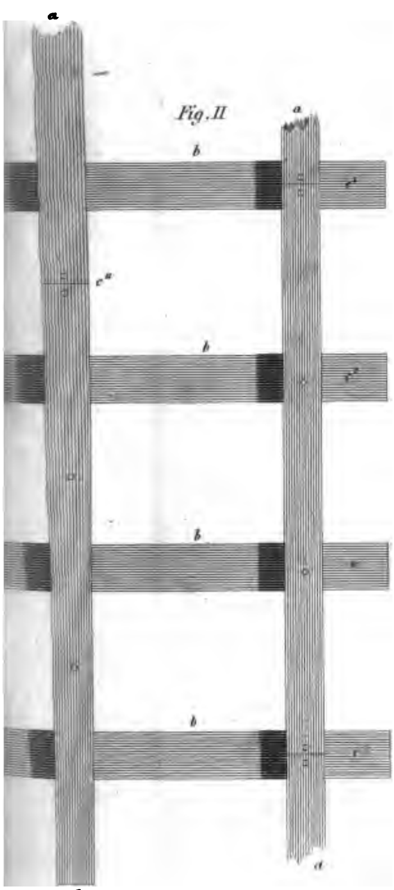
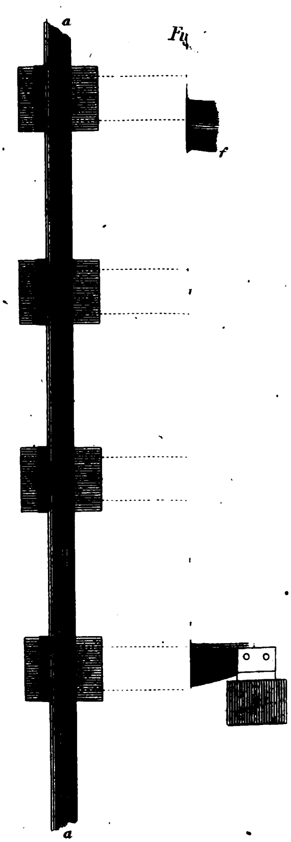


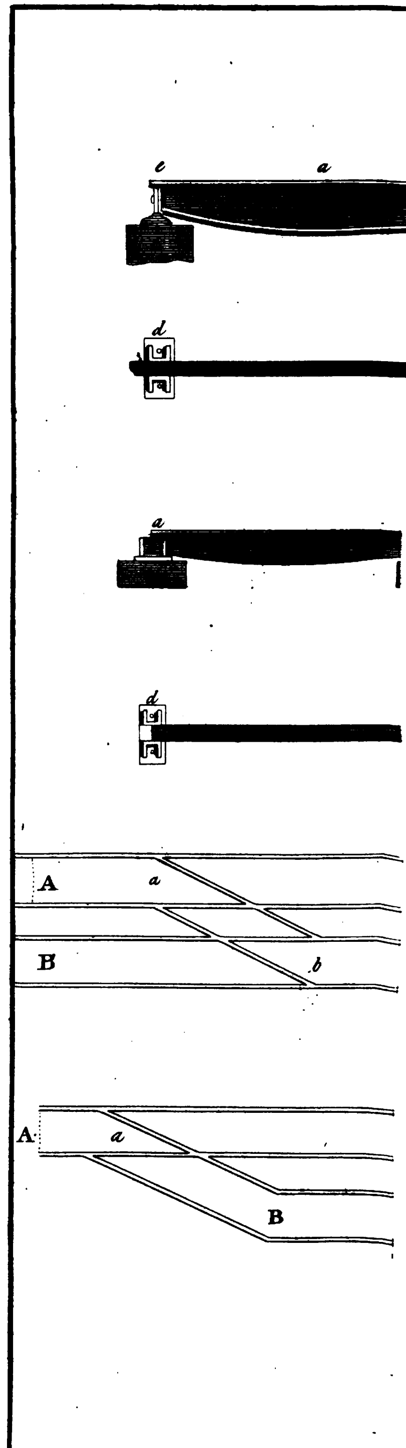
Fig.II



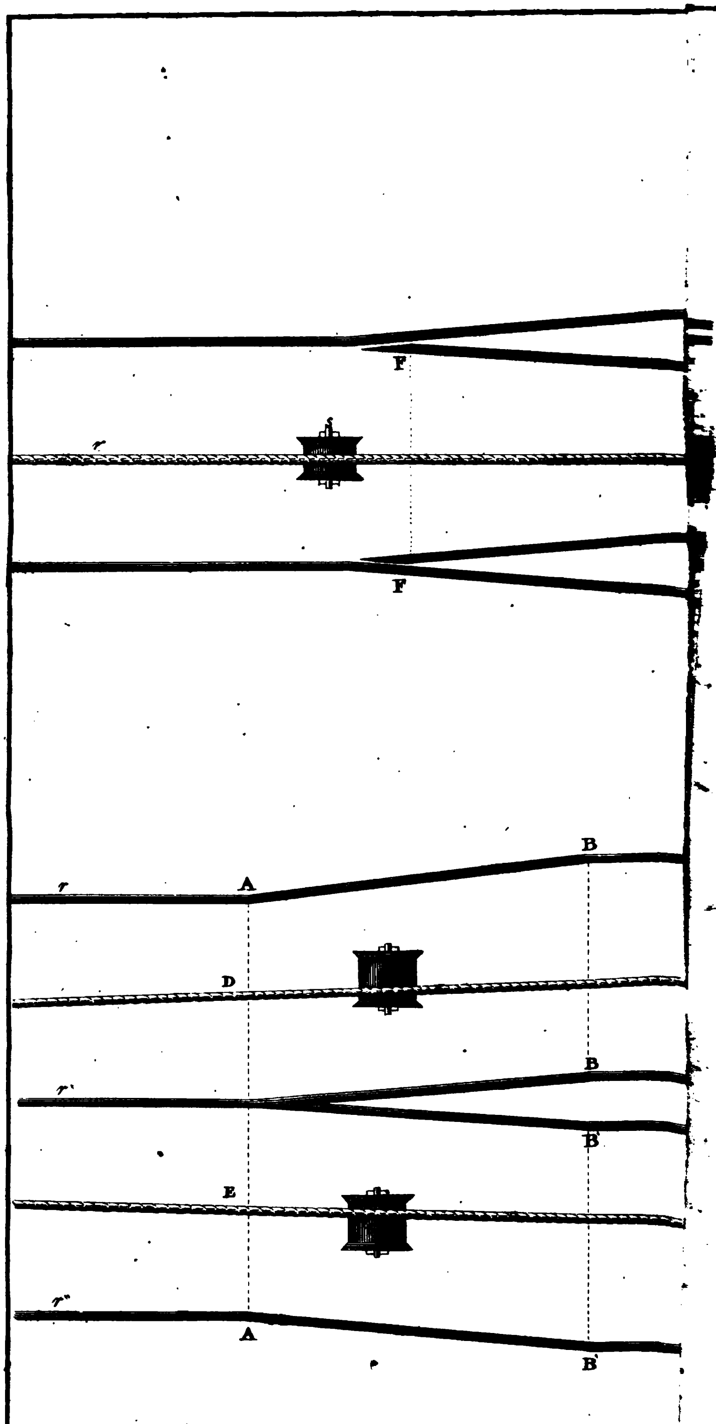
Fi



352 Strand



Drawn by E. Galloway.



Drawn by E. Galloway

Fig. I

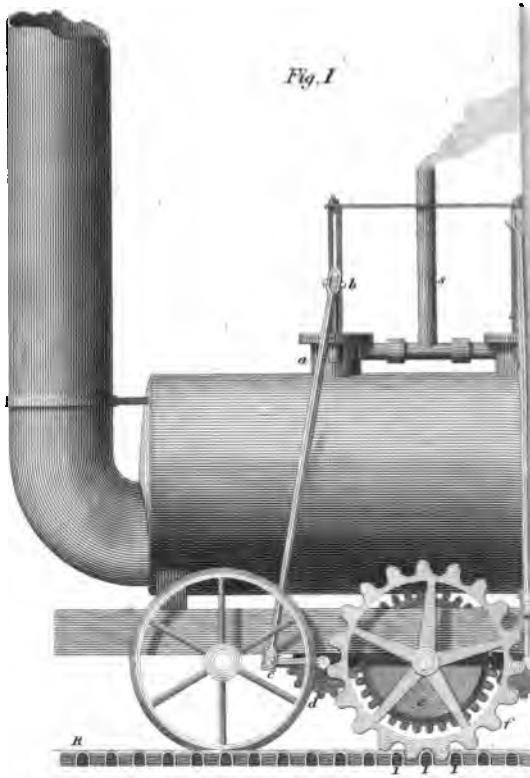
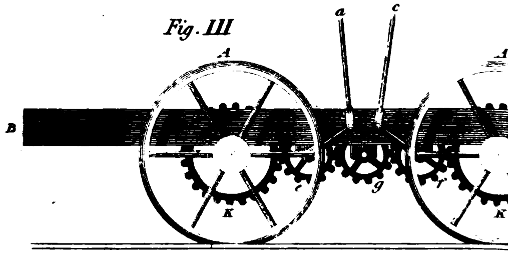
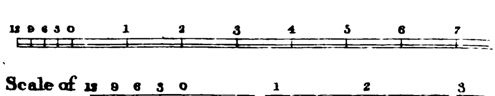


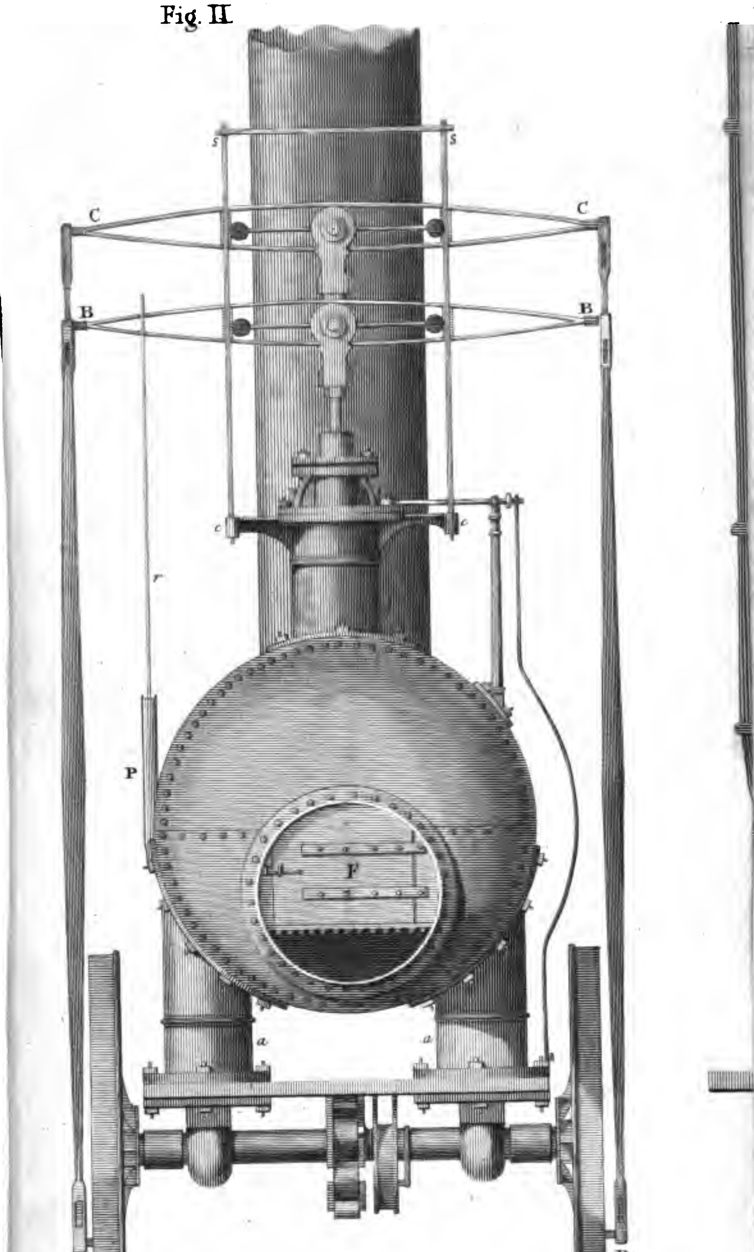
Fig. III



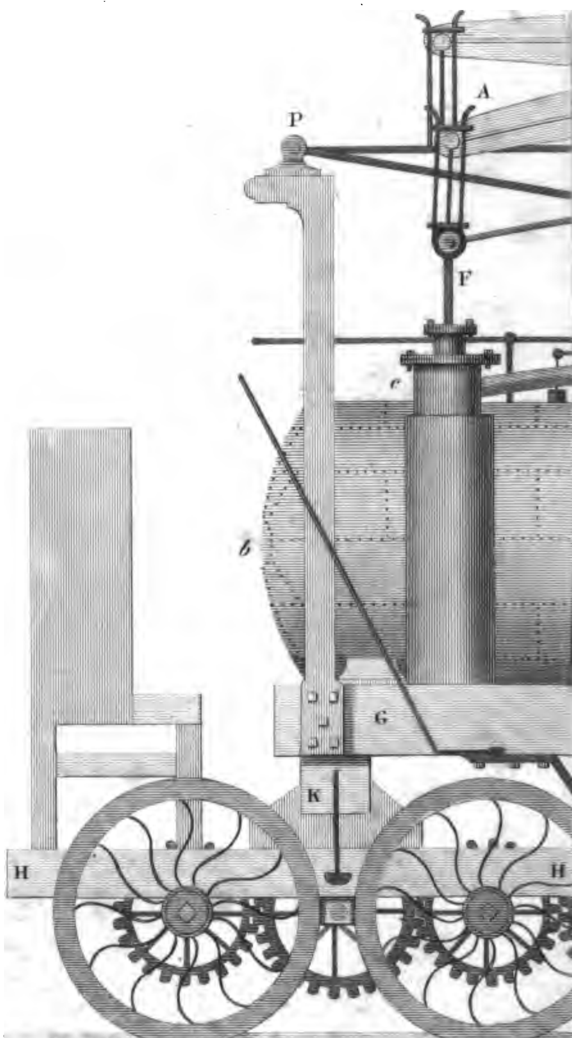


Scale of

Fig. II



[Dra]wn by E. Galloway.



Drawn by Thos. Johnson